

# **The Impacts of Energy Subsidy Reform and Determinants of Successful Outcomes: A Focus on Saudi Arabia**

**Anwar A. Gasim**

Institute for Sustainable Resources  
The Bartlett School of Environment, Energy and Resources  
University College London (UCL)

A thesis submitted for the degree of  
**Doctor of Philosophy**

June 2025

## **Declaration**

I, Anwar A. Gasim, confirm that the work presented in my thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

# Abstract

Saudi Arabia is a leading oil and gas producer and one of the largest energy consumers in the Middle East. Its energy demand and carbon dioxide emissions have risen sharply over the past decades, with population growth, economic development, and energy subsidies being key drivers. Such growth in energy demand is not sustainable. Energy subsidy reform is a tool that policymakers can use to encourage resource, fiscal, and environmental sustainability. Saudi Arabia recently implemented two waves of energy subsidy reform, and it appears to have plans for further reforms. However, such reforms can be difficult to implement. Policymakers need an in-depth understanding of the impacts of energy subsidy reform to move forward with implementation. They also need an understanding of the factors that lead to successful or unsuccessful reform outcomes.

This thesis models the impacts of energy subsidy reform in Saudi Arabia. I start by quantifying the consumer response to changes in the prices of energy products. I use the structural time series model to econometrically model energy demand across five sectors and 15 energy products in Saudi Arabia. I then employ the estimated price elasticities in microeconomic analyses to measure the fiscal, economic, environmental, and welfare impacts of past and future reforms.

This thesis also examines the factors that determine reform outcomes through a global review of past attempts at reform. I define a successful energy subsidy reform as one that does not lead to social unrest or is not reversed. I build a global dataset capturing countries' experiences with reform, on which I draw lessons and run logistic regressions. Qualitative and quantitative analyses are thus combined to understand how factors like the size of the energy price increase, economic performance, or the quality of governance influence the odds of a successful reform outcome.

# Impact Statement

Climate change is one of the defining issues facing our world. In 2015, countries ratified the Paris Agreement, agreeing to limit the global average temperature increase to below two degrees Celsius ( $^{\circ}\text{C}$ ) above pre-industrial levels while pursuing efforts towards a goal of  $1.5^{\circ}\text{C}$ . A portfolio of climate change policies will likely be needed to achieve the objectives of the Paris Agreement. Energy subsidy reform (also referred to as fossil fuel subsidy reform) is widely seen as a critical policy instrument for combatting climate change.

However, many countries face challenges in measuring the impacts of energy subsidy reform and achieving successful implementation. This thesis yields insights for policymakers seeking to reform energy subsidies, focusing on Saudi Arabia, a Group of Twenty (G20) economy with large energy subsidies according to organizations like the International Energy Agency and the International Monetary Fund. The insights from this thesis can inform policymakers in Saudi Arabia and beyond, enabling more effective public policy design and delivery.

Within academia, this thesis yields several benefits. It highlights gaps in energy subsidy reform research, answers important questions to tackle those gaps, and presents new methods for answering those questions. With regard to research methodologies, this thesis uses the Structural Time Series Model (STSM), a method that has seen relatively limited use in applied research compared to other econometric methods. I demonstrate the importance of using the STSM to obtain unbiased price and income elasticities. My price and income elasticities for Saudi Arabia are essential inputs needed to conduct many impact analyses. These elasticities can also be used to parameterize energy models for Saudi Arabia, which can answer further research questions. This thesis also provides a novel approach to measuring the fiscal impacts of energy subsidy reform.

Beyond academia, the primary benefits of this thesis lie within the sphere of public policymaking. For example, my work on the climate mitigation impacts of energy subsidy reform in Saudi Arabia has been used in advisory work at KAPSARC to inform the country's development of its climate mitigation targets and its selection of climate policy instruments for achieving those targets. My work on the lessons learned from past energy subsidy reforms and the determinants of successful

outcomes has also been used to inform the government's potential plans for future reforms.

While the insights from this thesis have already impacted energy policymaking in Saudi Arabia, they can also benefit policymakers in other countries with energy subsidies. The insights can also inform the effective implementation of other price-based policy instruments, such as a carbon tax, which will be necessary for combatting climate change and meeting national and global climate goals.

# Acknowledgments

A lot has changed over the last 12 years. In 2012, in my early 20s, I submitted a thesis to complete my MSc degree in electrical engineering. In 2024, in my mid-30s, I write these acknowledgments for my PhD thesis while reflecting on these last 12 years. Back then, I wasn't sure whether I would pursue a PhD, but it felt like a distinct possibility as I enjoyed research and had just accepted a job offer to work as a researcher at KAPSARC, an energy economics think tank in Riyadh, Saudi Arabia.

To get started, I would not be in this position to submit my PhD thesis without the support of my supervisor, Paul Ekins. I am deeply grateful to him for believing in my potential and supporting my application to pursue a non-resident PhD at UCL, allowing me to align my full-time job as an energy economics researcher at KAPSARC with a full-time PhD at UCL. I appreciate his mentorship these last few years, his wealth of knowledge he is always happy to offer, and his efforts to build a deeper and more meaningful relationship. Whenever I see the UCL logo, I fondly recall Paul's invitation to me and my wife to share some drinks in the Housman room at UCL during one of my university visits.

Doing a non-resident PhD has been a fantastic opportunity. It allowed me to simultaneously benefit from the expertise of world-leading academics at UCL and experts at KAPSARC. It gave me access to wide-ranging resources through UCL and KAPSARC's libraries. It enabled me to turn my academic research into policy impact through KAPSARC's advisory arm. But as with all things in life, these benefits did come at a cost. For each manuscript I prepared, I had to respond to feedback from my UCL supervisors and KAPSARC directors. For each milestone, I had to record it on the UCL Research Log and KAPSARC's Pure system. More benefits on the one hand and more costs on the other, but this was a case of benefits far exceeding costs.

I am also grateful to Paolo Agnolucci, my primary supervisor, for his support. His knowledge and attention to detail have helped elevate my research, and I've learned from him how to conduct more thorough analyses, tell better stories, and write more impactful papers.

Taking a step back to before my PhD, I would like to express my gratitude to Lester Hunt, my former research director and mentor at KAPSARC. He helped develop my energy demand modelling skills and put me on this path to doing a PhD that tackles the critical issue of energy subsidy reform, and he has continued to offer mentorship ever since.

Reflecting on my PhD, I've learned so many things. Although I already knew how to do research and publish journal papers before starting my PhD, I've become much better at it these last few years. I've been challenged to learn new methods, tell better stories, and publish more impactful papers. One of the most significant things I've gained from this PhD is a stronger ability to persevere – to consistently put in the required efforts even when circumstances are difficult.

In March 2024, my wife and teammate in life, Alia Alrabghy, gave birth to our wonderful baby boy, who we named Anmar, after a very challenging pregnancy. Looking towards the future, I often daydream about the things we can teach our son. I find myself thinking about the skills he needs to build a happy, healthy, and successful life, and among them is grit and perseverance. I hope to be able to teach him those skills, and I will share with him when he grows up my belief that if someone perseveres in an area with enough passion and attention to detail, they can create something beautiful, powerful, or impactful, as I hope this thesis will be.

Reflecting on my abilities, I can't help but think of my parents and their immense efforts to instill in me the skills that I have today. I am eternally grateful for their dedication to my learning. I still fondly recall my mom, Kawther Halloumah, teaching me mathematics, language, and science during primary school and encouraging me to be top of my class – an attitude that helped me excel academically. (She was also a phenomenal teacher!) I vividly remember the countless popular science books and magazines my dad, Abdulhameed Gasim, would buy for me as a kid and how he would encourage me to read, read, and read. (He also enjoyed starting thought-provoking conversations with us from a young age!) My parents' combined efforts produced within me an extreme fascination with the natural world that I've carried ever since. Thanks to my parents, I've reached this point in my life, and I am forever grateful to them.

I must also offer special words to someone I miss dearly every day, someone who helped shape me into who I am. My brother and closest friend, Sami Gasim, who was less than two years younger than me, passed away in 2015. I would not be who I am today without having grown up alongside him, and I would not have achieved what I have without all the lessons I learned from him despite his younger age. He remains the sharpest, funniest, wittiest, and most authentic human I have ever met, someone who can walk into people's hearts in a heartbeat. Without his influence on my life, I would not have reached this point, and I am forever grateful to him.

Learning from younger siblings appears to be a theme, as I am also grateful to Deema, my much younger sister, who I try to teach life lessons and learn new things from along the way.

I would also like to thank friends and colleagues for their direct or indirect support throughout my PhD. Walid Matar is a leading energy systems modeler at KAPSARC and someone who I can always count on for deep and thought-provoking discussions. It was precisely such a series of conversations that led us to develop a novel method to measure energy subsidies, as presented in Chapter 3 of my thesis. Lama Yaseen, a world-class data scientist at KAPSARC, supported my assembling of a comprehensive dataset on energy subsidy reform episodes, on which I ran the logistic regressions presented in Chapter 5 of this thesis. Nader AlKathiri, a friend who started his PhD at Sussex just before I did, has been a much-needed "PhD buddy" over the last few years, someone with whom I've been able to share all the ups and downs of doing a PhD. Jeyhun Mikayilov is a world-class econometrician at KAPSARC who is always open to discussing econometric methods and teaching me more about the underlying mathematics. Nora Nezamuddin, Ryan Al Yamani, and Abdulelah Darandary are friends whom I can always count on for an insightful discussion on any research topic. Nawaf Al Nafisee has been a consistent teammate on the football pitch, ensuring that I had a foundation of physical health that made my mind sharper. I am also grateful to many others at KAPSARC and UCL for their feedback on my research over the last four to five years. The list from KAPSARC includes Fahad Alajlan, Axel Pierru, Mohamad Hejazi, Mohammad Aldubyan, Fateh Belaid, Mari Luomi, Abdulaziz Alzoman, Muhammad Javid, Rami Shabaneh, and Rubal Dua. The list from UCL includes Neil Strachan, Alvaro Calzadilla Rivera, and Vincenzo de Lipsis, who is now at the University of Southampton and contributed to

my early PhD discussions with my supervisors. Last but certainly not least, I would like to thank KAPSARC for supporting my PhD financially.

I hope that this thesis can create a big positive impact. For all the benefits that it may generate, I dedicate them to Sami, Anmar, Alia, Deema, and my parents.

## **Research Paper Declaration Forms**

## Form 1

# UCL Research Paper Declaration Form

referencing the doctoral candidate's own published work(s)

*Please use this form to declare if parts of your thesis are already available in another format, e.g. if data, text, or figures:*

- *have been uploaded to a preprint server*
- *are in submission to a peer-reviewed publication*
- *have been published in a peer-reviewed publication, e.g. journal, textbook.*

*This form should be completed as many times as necessary. For instance, if you have seven thesis chapters, two of which containing material that has already been published, you would complete this form twice.*

### 1. For a research manuscript that has already been published (if not yet published, please skip to section 2)

#### a) What is the title of the manuscript?

Modeling final energy demand and the impacts of energy price reform in Saudi Arabia

#### b) Please include a link to or doi for the work

<https://doi.org/10.1016/j.eneco.2023.106589>

#### c) Where was the work published?

Energy Economics

#### d) Who published the work? (e.g. OUP)

Elsevier

#### e) When was the work published?

April 2023 (available online from February 2023)

#### f) List the manuscript's authors in the order they appear on the publication

Anwar A. Gasim, Paolo Agnolucci, Paul Ekins, and Vincenzo de Lipsis

#### g) Was the work peer reviewed?

Yes, it was

#### h) Have you retained the copyright?

Yes, I have retained the copyright. The paper was published open access under the terms of the Creative Commons CC-BY license, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited

#### i) Was an earlier form of the manuscript uploaded to a preprint server? (e.g. medRxiv). If 'Yes', please give a link or doi)

Yes, <https://dx.doi.org/10.2139/ssrn.4005959>

If 'No', please seek permission from the relevant publisher and check the box next to the below statement:



*I acknowledge permission of the publisher named under 1d to include in this thesis portions of the publication named as included in 1c.*

**2. For a research manuscript prepared for publication but that has not yet been published** (if already published, please skip to section 3)

- a) **What is the current title of the manuscript?**
- b) **Has the manuscript been uploaded to a preprint server?** (e.g. medRxiv; if 'Yes', please give a link or doi)
- c) **Where is the work intended to be published?** (e.g. journal names)
- d) **List the manuscript's authors in the intended authorship order**
- e) **Stage of publication** (e.g. in submission)

**3. For multi-authored work, please give a statement of contribution covering all authors** (if single-author, please skip to section 4)

**Anwar A. Gasim:** I conceptualized the work, collected the data, conducted the literature review, selected and applied the methodology, ran the formal analysis, visualized the data, wrote the original draft of the manuscript, and reviewed and edited the final manuscript.

**Paolo Agnolucci:** Paolo supervised my work and reviewed and edited the final manuscript.

**Paul Ekins:** Paul supervised my work and reviewed and edited the final manuscript.

**Vincenzo De Lipsis:** Vincenzo contributed to the early discussions alongside my supervisors and reviewed and edited the final manuscript.

**4. In which chapter(s) of your thesis can this material be found?**

Some material from this paper can be found in Chapter 1's literature review. The energy demand modelling material can be found in Chapter 2, while the impact analysis can be found in Chapter 3, where I apply the impact analysis methods more comprehensively.

5. **e-Signatures confirming that the information above is accurate** (this form should be co-signed by the supervisor/ senior author unless this is not appropriate, e.g. if the paper was a single-author work)

*Candidate*

Anwar Gasim

*Date:*

12/08/2024

*Supervisor/ Senior Author (where appropriate)*

Paul Ekins

*Date*

19/08/24

## Form 2

# UCL Research Paper Declaration Form

referencing the doctoral candidate's own published work(s)

*Please use this form to declare if parts of your thesis are already available in another format, e.g. if data, text, or figures:*

- *have been uploaded to a preprint server*
- *are in submission to a peer-reviewed publication*
- *have been published in a peer-reviewed publication, e.g. journal, textbook.*

*This form should be completed as many times as necessary. For instance, if you have seven thesis chapters, two of which containing material that has already been published, you would complete this form twice.*

### 1. For a research manuscript that has already been published (if not yet published, please skip to section 2)

**a) What is the title of the manuscript?**

Revisiting Energy Subsidy Calculations: A Focus on Saudi Arabia

**b) Please include a link to or doi for the work**

<https://doi.org/10.5547/01956574.44.1.agas>

**c) Where was the work published?**

The Energy Journal

**d) Who published the work? (e.g. OUP)**

IAEE (International Association for Energy Economics)

**e) When was the work published?**

First published online January 1, 2023

**f) List the manuscript's authors in the order they appear on the publication**

Anwar A. Gasim and Walid Matar

**g) Was the work peer reviewed?**

Yes, it was

**h) Have you retained the copyright?**

Yes, I have retained the copyright. The paper was published open access under the terms of the Creative Commons CC-BY 4.0 license, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited

**i) Was an earlier form of the manuscript uploaded to a preprint server? (e.g. medRxiv). If 'Yes', please give a link or doi)**

No

If 'No', please seek permission from the relevant publisher and check the box next to the below statement:



*I acknowledge permission of the publisher named under 1d to include in this thesis portions of the publication named as included in 1c.*

**2. For a research manuscript prepared for publication but that has not yet been published** (if already published, please skip to section 3)

- a) **What is the current title of the manuscript?**
- b) **Has the manuscript been uploaded to a preprint server?** (e.g. medRxiv; if 'Yes', please give a link or doi)
- c) **Where is the work intended to be published?** (e.g. journal names)
- d) **List the manuscript's authors in the intended authorship order**
- e) **Stage of publication** (e.g. in submission)

**3. For multi-authored work, please give a statement of contribution covering all authors** (if single-author, please skip to section 4)

**Anwar A. Gasim:** I conceptualized the work, conducted the literature review, collected the data, developed the methodology, ran the formal analysis, visualized the data, wrote the original draft of the manuscript, and reviewed and edited the final manuscript.

**Walid Matar:** Walid collected the data, developed the methodology, ran the formal analysis, wrote the original draft of the manuscript, and reviewed and edited the final manuscript.

**4. In which chapter(s) of your thesis can this material be found?**

Some material from this paper can be found in Chapter 1's literature review. Most of the material can be found in Chapter 3, where I present the methodology developed jointly and then apply it more widely across fuels and sectors.

5. **e-Signatures confirming that the information above is accurate** (this form should be co-signed by the supervisor/ senior author unless this is not appropriate, e.g. if the paper was a single-author work)

*Candidate*

Anwar Gasim

*Date:*

12/08/2024

*Supervisor/ Senior Author (where appropriate)*

Paul Ekins

*Date*

19/08/24

### Form 3

## UCL Research Paper Declaration Form

referencing the doctoral candidate's own published work(s)

*Please use this form to declare if parts of your thesis are already available in another format, e.g. if data, text, or figures:*

- *have been uploaded to a preprint server*
- *are in submission to a peer-reviewed publication*
- *have been published in a peer-reviewed publication, e.g. journal, textbook.*

*This form should be completed as many times as necessary. For instance, if you have seven thesis chapters, two of which containing material that has already been published, you would complete this form twice.*

**1. For a research manuscript that has already been published** (if not yet published, please skip to section 2)

- What is the title of the manuscript?**
- Please include a link to or doi for the work**
- Where was the work published?**
- Who published the work?** (e.g. OUP)
- When was the work published?**
- List the manuscript's authors in the order they appear on the publication**
- Was the work peer reviewed?**
- Have you retained the copyright?**
- Was an earlier form of the manuscript uploaded to a preprint server?** (e.g. medRxiv). If 'Yes', please give a link or doi)

If 'No', please seek permission from the relevant publisher and check the box next to the below statement:

☐

*I acknowledge permission of the publisher named under 1d to include in this thesis portions of the publication named as included in 1c.*

**2. For a research manuscript prepared for publication but that has not yet been published** (if already published, please skip to section 3)

**a) What is the current title of the manuscript?**

Lessons from an International Review of Successful and Unsuccessful Energy Subsidy Reforms

**b) Has the manuscript been uploaded to a preprint server?** (e.g. medRxiv; if 'Yes', please give a link or doi)

Yes, a working paper has been uploaded at the following link:

<https://www.kapsarc.org/research/publications/lessons-from-an-international-review-of-successful-and-unsuccessful-energy-subsidy-reforms/>

**c) Where is the work intended to be published?** (e.g. journal names)

The Energy Journal

**d) List the manuscript's authors in the intended authorship order**

Anwar A. Gasim, Paolo Agnolucci, and Paul Ekins

**e) Stage of publication** (e.g. in submission)

Journal paper undergoing peer review

**3. For multi-authored work, please give a statement of contribution covering all authors** (if single-author, please skip to section 4)

**Anwar A. Gasim:** I conceptualized the work, conducted the literature review, collected the data, developed the methodology, ran the formal analysis, visualized the data, wrote the original draft of the manuscript, and reviewed and edited the final manuscript.

**Paolo Agnolucci:** Paolo conceptualized the study, supervised my work, and reviewed and edited the final manuscript.

**Paul Ekins:** Paul conceptualized the study, supervised my work, and reviewed and edited the final manuscript.

**4. In which chapter(s) of your thesis can this material be found?**

Some material from this manuscript can be found in Chapter 1's literature review. Most of the material can be found in Chapter 4.

**5. e-Signatures confirming that the information above is accurate** (this form should be co-signed by the supervisor/ senior author unless this is not appropriate, e.g. if the paper was a single-author work)

*Candidate*

Anwar Gasim

*Date:*

12/08/2024

*Supervisor/ Senior Author (where appropriate)*

Paul Ekins

*Date*

19/08/24

## Form 4

# UCL Research Paper Declaration Form

referencing the doctoral candidate's own published work(s)

*Please use this form to declare if parts of your thesis are already available in another format, e.g. if data, text, or figures:*

- *have been uploaded to a preprint server*
- *are in submission to a peer-reviewed publication*
- *have been published in a peer-reviewed publication, e.g. journal, textbook.*

*This form should be completed as many times as necessary. For instance, if you have seven thesis chapters, two of which containing material that has already been published, you would complete this form twice.*

**1. For a research manuscript that has already been published** (if not yet published, please skip to section 2)

- What is the title of the manuscript?**
- Please include a link to or doi for the work**
- Where was the work published?**
- Who published the work?** (e.g. OUP)
- When was the work published?**
- List the manuscript's authors in the order they appear on the publication**
- Was the work peer reviewed?**
- Have you retained the copyright?**
- Was an earlier form of the manuscript uploaded to a preprint server?** (e.g. medRxiv). If 'Yes', please give a link or doi)

If 'No', please seek permission from the relevant publisher and check the box next to the below statement:

☐

*I acknowledge permission of the publisher named under 1d to include in this thesis portions of the publication named as included in 1c.*

**2. For a research manuscript prepared for publication but that has not yet been published** (if already published, please skip to section 3)

**a) What is the current title of the manuscript?**

The determinants of successful energy subsidy reforms: A logistic regression analysis

**b) Has the manuscript been uploaded to a preprint server?** (e.g. medRxiv; if 'Yes', please give a link or doi)

Yes, a working paper has been uploaded at the following link:

<https://www.kapsarc.org/research/publications/the-determinants-of-successful-energy-subsidy-reforms-a-logistic-regression-analysis/>

**c) Where is the work intended to be published?** (e.g. journal names)

Energy Policy or World Development

**d) List the manuscript's authors in the intended authorship order**

Anwar A. Gasim, Paolo Agnolucci, Paul Ekins, and Lama Yaseen

**e) Stage of publication** (e.g. in submission)

In submission

**3. For multi-authored work, please give a statement of contribution covering all authors** (if single-author, please skip to section 4)

**Anwar A. Gasim:** I conceptualized the work, conducted the literature review, collected the data, developed the methodology, ran the formal analysis, visualized the data, wrote the original draft of the manuscript, and reviewed and edited the final manuscript.

**Paolo Agnolucci:** Paolo conceptualized the study, supervised my work, and reviewed and edited the final manuscript.

**Paul Ekins:** Paul conceptualized the study, supervised my work, and reviewed and edited the final manuscript.

**Lama Yaseen:** Lama collected data, conducted data curation, and reviewed and edited the final manuscript.

**4. In which chapter(s) of your thesis can this material be found?**

All the material can be found in Chapter 5.

**5. e-Signatures confirming that the information above is accurate** (this form should be co-signed by the supervisor/ senior author unless this is not appropriate, e.g. if the paper was a single-author work)

*Candidate*

Anwar Gasim

*Date:*

12/08/2024

*Supervisor/ Senior Author (where appropriate)*

Paul Ekins

*Date*

19/08/24

# Table of Contents

|                                                                                                      |           |
|------------------------------------------------------------------------------------------------------|-----------|
| <b>Declaration.....</b>                                                                              | <b>2</b>  |
| <b>Abstract.....</b>                                                                                 | <b>3</b>  |
| <b>Impact Statement .....</b>                                                                        | <b>4</b>  |
| <b>Acknowledgments.....</b>                                                                          | <b>6</b>  |
| <b>Research Paper Declaration Forms.....</b>                                                         | <b>10</b> |
| <b>Table of Contents .....</b>                                                                       | <b>23</b> |
| <b>Table of Figures.....</b>                                                                         | <b>27</b> |
| <b>Table of Tables .....</b>                                                                         | <b>29</b> |
| <b>Chapter 1: General Introduction .....</b>                                                         | <b>32</b> |
| 1.1 Energy Subsidies: Definitions and Issues.....                                                    | 36        |
| 1.2 The Rationale for Introducing Energy Subsidies.....                                              | 41        |
| 1.3 The Consequences of Energy Subsidies and Drivers of Their Reform.....                            | 42        |
| 1.4 The Challenges to Implementing Energy Subsidy Reforms.....                                       | 45        |
| 1.5 A Focus on Saudi Arabia: Background and Context of Energy Subsidies and<br>Their Reform.....     | 47        |
| 1.6 Thesis Research Questions and Structure .....                                                    | 50        |
| <b>Chapter 2: Modelling Energy Demand in Saudi Arabia and Measuring the Price<br/>Response .....</b> | <b>52</b> |
| 2.1. Introduction .....                                                                              | 52        |
| 2.2. Background on Saudi Final Energy Demand .....                                                   | 54        |
| 2.3. Related Literature .....                                                                        | 55        |
| 2.4 Methods and Data .....                                                                           | 59        |
| 2.4.1 Econometric method .....                                                                       | 59        |
| 2.4.2 Time series data.....                                                                          | 62        |
| 2.5 Econometric Results.....                                                                         | 66        |

|                                                                                                                     |           |
|---------------------------------------------------------------------------------------------------------------------|-----------|
| 2.5.1 Overview of results.....                                                                                      | 66        |
| 2.5.2 Transport sector discussion .....                                                                             | 75        |
| 2.5.3 Residential sector discussion .....                                                                           | 77        |
| 2.5.4 Commercial and governmental sector discussion .....                                                           | 78        |
| 2.5.5 Industrial sector discussion .....                                                                            | 79        |
| 2.5.6 Non-energy use (feedstock) sector discussion.....                                                             | 82        |
| 2.6 Conclusion.....                                                                                                 | 84        |
| <b>Chapter 3: The Economic, Environmental, and Fiscal Impacts of Energy<br/>Subsidy Reform in Saudi Arabia.....</b> | <b>86</b> |
| 3.1 Introduction .....                                                                                              | 86        |
| 3.2 Background on Energy Subsidy Reform Efforts in Saudi Arabia .....                                               | 87        |
| 3.3. Conceptual Framework.....                                                                                      | 92        |
| 3.3.1 Measuring the economic impacts of energy subsidy reform .....                                                 | 92        |
| 3.3.2 Measuring the emission impacts of energy subsidy reform.....                                                  | 94        |
| 3.3.3 Measuring the fiscal costs and impacts of energy subsidy reform .....                                         | 95        |
| 3.4 Literature Review .....                                                                                         | 97        |
| 3.4.1 Welfare impacts of energy subsidy reform from the literature .....                                            | 97        |
| 3.4.2 Emission impacts of energy subsidy reform from the literature .....                                           | 100       |
| 3.4.3 Fiscal costs and impacts of energy subsidy reform from the literature ...                                     | 101       |
| 3.5 Methods.....                                                                                                    | 103       |
| 3.5.1 Measuring the welfare changes due to energy subsidy reform .....                                              | 103       |
| 3.5.2 Measuring the emission reductions due to energy subsidy reform.....                                           | 106       |
| 3.5.3 Measuring the fiscal impacts due to energy subsidy reform.....                                                | 106       |
| 3.6 Data .....                                                                                                      | 113       |
| 3.7 Results.....                                                                                                    | 117       |
| 3.7.1 Welfare impact analysis results.....                                                                          | 117       |

|                                                                                                                   |            |
|-------------------------------------------------------------------------------------------------------------------|------------|
| 3.7.2 Emission impact analysis results.....                                                                       | 125        |
| 3.7.3 Sensitivity analysis: welfare and emission impacts .....                                                    | 127        |
| 3.7.4 Fiscal impact analysis results.....                                                                         | 129        |
| 3.7.5 How additional fuel exports influence the international market price and the<br>fiscal impacts.....         | 131        |
| 3.8 Conclusion .....                                                                                              | 140        |
| <b>Chapter 4: Lessons for Successful Energy Subsidy Reforms .....</b>                                             | <b>143</b> |
| 4.1 Introduction .....                                                                                            | 143        |
| 4.2 Lessons from the Literature .....                                                                             | 144        |
| 4.3 Methodology .....                                                                                             | 147        |
| 4.3.1 Definitions and scope.....                                                                                  | 147        |
| 4.3.2 Building a database of news articles and extracting information .....                                       | 149        |
| 4.3.3 Challenges with data collection using online news databases .....                                           | 151        |
| 4.4 Results and Discussion .....                                                                                  | 156        |
| 4.4.1 What does the database reveal about the six lessons from the literature?<br>.....                           | 156        |
| 4.4.2 What additional lessons does the database provide? .....                                                    | 166        |
| 4.5. Conclusion .....                                                                                             | 169        |
| <b>Chapter 5: The Determinants of Successful Energy Subsidy Reforms: A<br/>Logistic Regression Analysis .....</b> | <b>172</b> |
| 5.1 Introduction .....                                                                                            | 172        |
| 5.2 Literature Review .....                                                                                       | 173        |
| 5.3 Data and Methods .....                                                                                        | 177        |
| 5.3.1 Dataset construction .....                                                                                  | 177        |
| 5.3.2 Dataset description .....                                                                                   | 180        |
| 5.3.3 Logistic regression methods.....                                                                            | 188        |
| 5.4 Logistic Regression Results .....                                                                             | 193        |

|                                                                   |            |
|-------------------------------------------------------------------|------------|
| 5.4.1 Results for social unrest as the dependent variable .....   | 193        |
| 5.4.2 Results for reform reversal as the dependent variable ..... | 204        |
| 5.5 Conclusion .....                                              | 212        |
| <b>Chapter 6: Conclusions .....</b>                               | <b>214</b> |
| 6.1 Rationale for Research .....                                  | 214        |
| 6.2 Research Questions .....                                      | 215        |
| 6.3 Summary and Implications of Results .....                     | 215        |
| 6.4 Future Research .....                                         | 220        |
| <b>References .....</b>                                           | <b>222</b> |
| <b>Author Contribution Statement .....</b>                        | <b>261</b> |
| <b>Appendices .....</b>                                           | <b>264</b> |
| Appendix A. Unit Root and Cointegration Tests .....               | 264        |
| Appendix B: Point Elasticities Versus Arc Elasticities .....      | 269        |

## Table of Figures

|                                                                                                                                     |     |
|-------------------------------------------------------------------------------------------------------------------------------------|-----|
| <b>Figure 1</b> Breakdown of final energy consumption in Saudi Arabia. ....                                                         | 55  |
| <b>Figure 2</b> UEDTs of the final models for the transport sector. ....                                                            | 76  |
| <b>Figure 3</b> UEDTs of the final models for the residential sector. ....                                                          | 78  |
| <b>Figure 4</b> UEDT of the final model for the commercial and governmental sector. ....                                            | 79  |
| <b>Figure 5</b> UEDTs of the final models for the industrial sector. ....                                                           | 81  |
| <b>Figure 6</b> UEDTs of the final models for the non-energy use sector. ....                                                       | 84  |
| <b>Figure 7</b> Real energy prices in Saudi Arabia between 2000 and 2018. ....                                                      | 91  |
| <b>Figure 8</b> Welfare gain in 2018 due to implemented gasoline subsidy reform versus size of gasoline price elasticity. ....      | 128 |
| <b>Figure 9</b> Avoided emissions in 2018 due to implemented gasoline subsidy reform versus size of gasoline price elasticity. .... | 128 |
| <b>Figure 10</b> Fiscal gain from full gasoline subsidy reform in 2018 at a range of elasticities. ....                             | 134 |
| <b>Figure 11</b> Fiscal gain from full diesel subsidy reform in 2018 at a range of elasticities. ....                               | 135 |
| <b>Figure 12</b> Fiscal gain from full kerosene subsidy reform in 2018 at a range of elasticities. ....                             | 136 |
| <b>Figure 13</b> Fiscal gain from full heavy fuel oil subsidy reform in 2018 at a range of elasticities. ....                       | 137 |
| <b>Figure 14</b> Fiscal gain from full LPG subsidy reform in 2018 at a range of elasticities. ....                                  | 138 |
| <b>Figure 15</b> Fiscal gain from full crude oil subsidy reform in 2018 at a range of elasticities. ....                            | 139 |
| <b>Figure 16</b> Illustrative query used in Nexis to search for relevant news articles. ....                                        | 150 |
| <b>Figure 17</b> Map of energy subsidy reform episodes found through the news-content-based search for the 1995-2022 period. ....   | 153 |
| <b>Figure 18</b> Energy subsidy reform episodes disaggregated by unrest outcome. ....                                               | 154 |

|                                                                                                                        |     |
|------------------------------------------------------------------------------------------------------------------------|-----|
| <b>Figure 19</b> Energy subsidy reform episodes disaggregated by reversal outcome. .                                   | 155 |
| <b>Figure 20</b> Energy subsidy reform outcomes disaggregated by compensation use.<br>.....                            | 185 |
| <b>Figure 21</b> The relationship between the arc and point price elasticities for a range of<br>price increases. .... | 270 |

## Table of Tables

|                                                                                                                                                                                |     |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|
| <b>Table 1</b> Price and income elasticities from studies that modelled energy demand in Saudi Arabia using econometric methods. ....                                          | 57  |
| <b>Table 2</b> Independent variables in the GUM for each energy demand equation. ....                                                                                          | 64  |
| <b>Table 3</b> Summary statistics for all the model variables. ....                                                                                                            | 65  |
| <b>Table 4</b> Final models estimated for the transport sector. ....                                                                                                           | 69  |
| <b>Table 5</b> Final models estimated for the residential sector. ....                                                                                                         | 70  |
| <b>Table 6</b> Final model estimated for the commercial & governmental sector. ....                                                                                            | 71  |
| <b>Table 7</b> Final models estimated for the industrial sector. ....                                                                                                          | 72  |
| <b>Table 8</b> Final models estimated for the non-energy use sector. ....                                                                                                      | 73  |
| <b>Table 9</b> A summary of the estimated coefficients and the types of estimated trends for each final model. ....                                                            | 74  |
| <b>Table 10</b> Nominal energy prices in Saudi Arabia between 2015 and 2018. ....                                                                                              | 90  |
| <b>Table 11</b> Ratio of Saudi fuel exports to global fuel consumption in 2018. ....                                                                                           | 117 |
| <b>Table 12</b> Illustrative gasoline prices across the two scenarios used to analyze the actual impacts of the implemented partial energy subsidy reforms. ....               | 118 |
| <b>Table 13</b> Illustrative gasoline prices across the two scenarios used to analyze the potential impacts of future full energy subsidy reforms ....                         | 119 |
| <b>Table 14</b> The actual and potential welfare impacts of energy subsidy reform using the long-run price elasticities. ....                                                  | 123 |
| <b>Table 15</b> The actual and potential welfare impacts of energy subsidy reform using the short-run price elasticities. ....                                                 | 124 |
| <b>Table 16</b> The annual avoided CO <sub>2</sub> emissions (in million tonnes) from actual and potential energy subsidy reforms using the long-run price elasticities. ....  | 126 |
| <b>Table 17</b> The annual avoided CO <sub>2</sub> emissions (in million tonnes) from actual and potential energy subsidy reforms using the short-run price elasticities. .... | 127 |
| <b>Table 18</b> The fiscal impacts (in billion 2010 USD) from actual and potential energy subsidy reforms using the long-run price elasticities. ....                          | 130 |

|                                                                                                                                                                                                  |     |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|
| <b>Table 19</b> The fiscal impacts (in billion 2010 USD) from actual and potential energy subsidy reforms using the short-run price elasticities. ....                                           | 131 |
| <b>Table 20</b> Fiscal gain from full gasoline subsidy reform in 2018 at specific estimated elasticities. ....                                                                                   | 133 |
| <b>Table 21</b> The fiscal impacts (in billion current USD) using the price-gap and refined method. ....                                                                                         | 140 |
| <b>Table 22</b> A list of news articles that were extracted before, during, and after Nigeria's energy subsidy reform episode implemented on January 1, 2012. ....                               | 158 |
| <b>Table 23</b> Estimated logistic regression models from the literature. ....                                                                                                                   | 175 |
| <b>Table 24</b> Number of observations by outcome and country in the dataset. ....                                                                                                               | 182 |
| <b>Table 25</b> Summary statistics, categorized by outcome, for the energy price increases that were implemented across all 400 episodes of energy subsidy reform. ....                          | 184 |
| <b>Table 26</b> Summary statistics, categorized by unrest outcome, for the economic, political, institutional, and governance variables in countries across all 400 implemented episodes. ....   | 186 |
| <b>Table 27</b> Summary statistics, categorized by reversal outcome, for the economic, political, institutional, and governance variables in countries across all 400 implemented episodes. .... | 187 |
| <b>Table 28</b> Estimated general models (using pooled estimator) and goodness-of-fit tests with different sets of dummy variables. ....                                                         | 197 |
| <b>Table 29</b> Estimated purposeful selection models (using pooled estimator) and goodness-of-fit tests with different sets of dummies. ....                                                    | 198 |
| <b>Table 30</b> Estimated parsimonious models (using pooled estimator) and goodness-of-fit tests. ....                                                                                           | 199 |
| <b>Table 31</b> Final model 2 logistic regression results using different estimators. ....                                                                                                       | 200 |
| <b>Table 32</b> Classification statistics for the preferred final social unrest model. ....                                                                                                      | 201 |
| <b>Table 33</b> Odds ratios for the final social unrest model. ....                                                                                                                              | 201 |
| <b>Table 34</b> Estimated general models (using pooled estimator) and goodness-of-fit tests with different sets of dummy variables. ....                                                         | 207 |

|                                                                                                                                                           |     |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------|-----|
| <b>Table 35</b> Estimated purposeful selection models (using pooled estimator) and goodness-of-fit tests with different sets of dummies.....              | 208 |
| <b>Table 36</b> Estimated parsimonious models (using different estimators) and goodness-of-fit tests.....                                                 | 209 |
| <b>Table 37</b> Classification statistics for the final reform reversal model.....                                                                        | 210 |
| <b>Table 38</b> Odds ratios for the final reform reversal model .....                                                                                     | 210 |
| <b>Table 39</b> The t-statistics from the Augmented Dickey-Fuller unit root tests .....                                                                   | 265 |
| <b>Table 40</b> The F-statistics from the F-Bounds test for cointegration, presented alongside the bounds at the 10% statistical significance level ..... | 267 |

# Chapter 1: General Introduction

Energy subsidy reform (also referred to as energy price reform or fossil fuel subsidy reform) is a policy tool that can promote fiscal, resource, and environmental sustainability. Studies have shown that the reduction or removal of energy subsidies can generate large fiscal, economic, health, and environmental benefits for a country (Black et al., 2023). The International Monetary Fund (IMF) estimated the global fiscal cost of energy subsidies in 2022 at 1.3 trillion United States Dollars (USD), which represents roughly 1.3% of global gross domestic product (GDP) in that year (Black et al., 2023).

Given the high fiscal costs that energy subsidies can impose on an economy, it is not surprising that fiscal pressures have historically been the primary drivers of energy subsidy reforms (Vagliasindi, 2013; Rentschler and Bazilian, 2017a, 2017b). These fiscal pressures often fluctuate depending on global and national circumstances. For example, in many oil-exporting countries, the collapse in international oil prices in late 2014 and the subsequent decrease in oil revenue for those governments triggered the implementation of energy subsidy reforms to improve the fiscal balance (Fattouh et al., 2016). In many oil-importing countries, reforms were undertaken when the fiscal burden from fuel subsidies became too large, generally during periods of high international oil prices, such as between late 2009 and early 2014 (Vagliasindi, 2013; Kojima, 2016).

Moving forward, climate change is expected to become an increasingly prominent driver for further energy subsidy reforms. Climate change is one of the defining issues currently facing our world. In 2015, 196 countries ratified the Paris Agreement (2015), agreeing to limit the global average temperature increase to below two degrees Celsius (°C) above pre-industrial levels while pursuing efforts towards a more ambitious goal of 1.5 °C above pre-industrial levels. A portfolio of climate change policies will likely be needed to achieve the objectives of the Paris Agreement, and energy subsidy reform is widely seen as a critical policy instrument for doing so. At the 26th Conference of the Parties (COP26), which took place in Glasgow in 2021, countries mentioned fossil fuel subsidy reform in the outcome agreement for the first time in the 26 years of the United Nations Framework Convention on Climate Change (UNFCCC) (UN Climate Change Conference, 2021).

The Glasgow Climate Pact stated the need to “phase-out of inefficient fossil fuel subsidies, while providing targeted support to the poorest and most vulnerable in line with national circumstances.”

Saudi Arabia is often found to have among the highest levels of energy subsidies globally, which has implications for the country’s economy, hydrocarbon resources, greenhouse gas (GHG) emissions, and fiscal balance. The IMF estimated Saudi Arabia’s energy subsidies in 2022 to be around 129 billion USD, roughly 10% of their global estimate (Black et al., 2023). According to the Energy Information Administration (EIA, 2023), Saudi Arabia was the world’s third-largest oil producer in 2022 and the world’s top oil exporter. It is also among the Middle East’s largest energy consumers and GHG emitters. According to the Energy Institute (EI, 2024), Saudi Arabia’s primary energy consumption grew from 23 to 271 million tonnes of oil equivalent (Mtoe) between 1970 and 2022, while energy-related carbon dioxide emissions (CO<sub>2</sub>) grew from 67 to 609 million tonnes (Mt) over the same period. Such rapid growth in domestic energy demand is not sustainable – whether looked at from a resource or environmental perspective. Lahn and Stevens (2011) examined Saudi Arabia’s growing domestic energy consumption and ran simulations that showed that, on its trajectory at the time, Saudi Arabia could “become a net importer of oil by 2038”, which would cause the country to lose one of its primary sources of fiscal revenue.

The concerns over resource and fiscal sustainability prompted two waves of partial energy price reform in Saudi Arabia, the first in 2016 and the second in 2018 (Fiscal Balance Program, 2016-2019). Energy price reform is arguably one of the most important initiatives under Saudi Vision 2030, an overarching strategy launched in 2016 to transform the country economically and socially (Saudi Vision 2030, 2016). Further waves of energy price reform could bring Saudi Arabia closer to achieving its economic, fiscal, and environmental sustainability goals.

However, implementing further energy subsidy reforms in Saudi Arabia is challenging. While some countries have successfully reformed energy subsidies, others that attempted to do so were forced to ‘backtrack’ and reverse their reforms, sometimes in response to widespread protests and rioting. For example, in only 2022, energy subsidy reforms were implemented by countries as varied as

Bangladesh (Paul, 2022), Haiti (CE Noticias Financieras English, 2022a), Indonesia (Associated Press Financial Wire, 2022), Kazakhstan (Eurasianet, 2022), Sri Lanka (Agence France Presse, 2022), and Tunisia (The Financial Express, 2022b). Most of these episodes triggered social unrest (Al Arabiya, 2022; CE Noticias Financieras English, 2022b; IANS-English, 2022; Widiyanto, 2022; World Socialist Web Site, 2022), while in Kazakhstan, the reform led to widespread protests, its reversal, the resignation of the government, and a state of emergency (Al Arabiya, 2022; Sullivan, 2022). These examples underscore how policymakers worldwide continue to face challenges in implementing energy subsidy reforms successfully.

Policymakers in Saudi Arabia and around the world that deal with energy subsidies need to understand the costs of energy subsidies, the impacts of energy subsidy reform, and how to design and implement such reforms effectively, given each country's political context and national circumstances. Guidance on these different facets of energy subsidy reform is needed to support policymakers in implementing energy subsidy reforms successfully, which could unlock massive economic, health, and environmental benefits globally.

This thesis is divided into four parts, each focusing on a different facet of energy subsidy reform, with the overarching goal of informing policymakers to help them deliver successful and durable energy subsidy reforms. Although this thesis focuses on Saudi Arabia, many of the insights are relevant for a much broader group of countries, given the prevalence of energy subsidies globally and growing drivers for their reform, particularly climate change mitigation.

The first part of this thesis seeks to understand how changes in energy prices affect energy demand, focusing on Saudi Arabia. Energy subsidy reform is an intervention that mainly causes consumers to reduce their energy use in response to higher domestic energy prices. To measure the impacts of energy subsidy reform, policymakers first need to understand this price response. Economists generally measure this price response by estimating a price elasticity, a metric that reflects how a marginal change in an energy price changes energy consumption. While some published price elasticity estimates exist for Saudi Arabia, there is a striking absence of estimates for many energy products. Moreover, the few existing estimates were primarily based on models that excluded time trends, which can lead

to biased price elasticity estimates. Although a few of the existing price elasticity estimates for Saudi Arabia were based on models that did include deterministic time trends, Hunt et al. (2003) have demonstrated that this can still lead to “seriously biased” elasticity estimates if the trends in energy demand are stochastic. Therefore, this thesis employs Harvey’s (1989) Structural Time Series Model (STSM) to obtain price elasticity estimates while allowing for potentially stochastic trends in energy demand. I estimate price elasticities across five end-use sectors and 15 energy products, including gasoline, diesel, natural gas, kerosene, liquefied petroleum gas (LPG), fuel oil, and electricity.

The second part of this thesis leverages the estimated price elasticities to model the economic, environmental, and fiscal impacts of energy subsidy reform in Saudi Arabia. Both partial and general equilibrium approaches have been used to measure these impacts (Ellis, 2010). For the economic and environmental impacts, this thesis adopts a partial equilibrium approach that rests on the estimated price elasticities. On the fiscal side, this thesis assesses both the fiscal cost of energy subsidies and the fiscal impacts of their reform. The magnitude of energy subsidies reflects their cost, which may be incurred entirely by the government, but it can also be incurred by other actors in the economy (Gooptu, 2018). This thesis focuses primarily on measuring the costs of subsidies to the Saudi government and the fiscal gains from partially or completely reforming them. In other words, this thesis seeks to measure how much revenue the Saudi government is foregoing due to energy subsidies and how much revenue can be gained from partial or complete energy subsidy reform. The fiscal costs of energy subsidies are generally measured using the price-gap method (Koplow, 2009), but this thesis goes further by developing a more generalized approach that better captures the revenue uplift by accounting for how energy subsidy reform in Saudi Arabia could influence international oil prices.

Having established the economic, environmental, and fiscal benefits of energy subsidy reform in Saudi Arabia, the third part of this thesis explores the question of how policymakers in the Kingdom and beyond can implement an energy subsidy reform successfully, avoiding undesirable outcomes like social unrest, which can often force policymakers to reverse the reform (Clements et al., 2013, 2014). This thesis reviews studies that drew lessons from past attempts at reform, synthesizing a set of recurrent lessons from the literature. It then expounds on these lessons and

draws further insights by constructing and reviewing an original dataset that comprises over 3000 news articles that capture the context, details, and outcomes of over 400 episodes of energy subsidy reform implemented worldwide in over 40 countries between 1995 and 2022. This dataset is rich with information on the decisions and circumstances across different countries that contributed to producing positive or negative outcomes following an attempt at energy subsidy reform.

The fourth part of this thesis continues with its global focus, leveraging the newly constructed dataset to conduct a quantitative analysis that measures the effects of different variables and national circumstances on the probability of achieving a successful reform outcome. In line with the literature (Chelminski, 2018), this thesis adopts a two-pronged definition of success, in which a subsidy reform is deemed successful if it does not lead to social unrest or it is not reversed. Despite the vast potential and challenges associated with further energy subsidy reform globally, there is surprisingly very little quantitative research on this topic (McCulloch et al., 2022). This thesis builds on the few existing studies by applying logistic regression analysis to the rich dataset that was constructed, which allows for quantifying the effects of a wide range of variables on the odds of social unrest or a reversal occurring following energy subsidy reform.

The remainder of this chapter provides a general literature review that discusses how energy subsidies are defined, the rationale for countries' introduction of energy subsidies, and the consequences and drivers of energy subsidy reform. This chapter then contextualizes Saudi Arabia's energy economy and energy subsidy reform efforts. Finally, it outlines the primary research questions and lays out the structure of the thesis.

## **1.1 Energy Subsidies: Definitions and Issues**

The definition of a subsidy varies from one source to another. According to the Oxford English Dictionary (2024), a subsidy is “money or a sum of money granted by the state or a public body to help keep down the price of a commodity or service, or to support something held to be in the public interest.” Merriam-Webster (2024) defines a subsidy as a “grant by a government to a private person or company to assist an enterprise deemed advantageous to the public.” While both definitions include the word grant, which suggests some financial transfer, they differ in several

ways. Most importantly, the former emphasizes the transfer of money to keep the price of a commodity low, while the latter is more general and emphasizes a transfer to give an advantage to the public.<sup>1</sup>

Economics textbooks can also be used to look for definitions of subsidies, given that they are economic instruments. For example, Bhattacharyya (2019) defines subsidies as “the difference between the price that would exist in a market in absence of any distortion or market failures and the price faced by consumers at a given time.” Mankiw (2023) defines a subsidy as “the opposite of a tax,” stating that it is “a payment to buyers and sellers to supplement income or reduce costs of production to provide an advantage to the recipient of the subsidy.”

The System of National Accounts (SNA, 2008), which guides governments to compile measures of economic activity, presents its definition of subsidies for inclusion in national accounts. The SNA defines subsidies as “current unrequited payments that government units ... make to enterprises on the basis of the levels of their production activities.” In contrast to the previously described definitions, the SNA’s definition is relatively narrow, capturing only subsidies that are given to producers. As stated in the SNA (2008), “subsidies are not payable to final consumers; current transfers that governments make directly to households as consumers are treated as social benefits.”

When defining subsidies, it can be helpful to distinguish between producer (or production) and consumer (or consumption) subsidies. Consumer subsidies generally exist when the price of a good or service for consumers is below some reference price, thereby benefitting consumers. On the other hand, producer subsidies generally exist when governments raise prices or lower production costs to benefit producers.

Steenblik (2003) provides a broad categorization of subsidies, where he classifies them around several dimensions: 1) the target of the subsidy, which could be consumers or producers; 2) the instrument used to provide support, whether it be budgetary expenditure or the foregoing of revenue; 3) the pathway of benefit, which could be direct or indirect; and 4) the purpose, which could be, for example,

---

<sup>1</sup> Both dictionaries also provide alternative definitions for the word subsidy. The Oxford English Dictionary provides seven definitions while Merriam-Webster provides three definitions.

providing households with better energy access, reducing energy poverty, or protecting domestic industries.

The World Trade Organization (WTO) offers one of the broadest definitions of subsidies. With 164 members (WTO, 2024), the WTO's definition is arguably the most widely accepted. WTO Members agree to the definition listed in Article 1 of the WTO's (1994) Agreement on Subsidies and Countervailing Measures (ASCM). This definition states that "a subsidy shall be deemed to exist if:

(a)(1) there is a financial contribution by a government or any public body within the territory of a Member (referred to in this Agreement as "government"), i.e. where:

(i) a government practice involves a direct transfer of funds (e.g. grants, loans, and equity infusion), potential direct transfers of funds or liabilities (e.g. loan guarantees);

(ii) government revenue that is otherwise due is foregone or not collected (e.g. fiscal incentives such as tax credits);

(iii) a government provides goods or services other than general infrastructure, or purchases goods;

(iv) a government makes payments to a funding mechanism, or entrusts or directs a private body to carry out one or more of the type of functions illustrated in (i) to (iii) above which would normally be vested in the government and the practice, in no real sense, differs from practices normally followed by governments;

or

(a)(2) there is any form of income or price support in the sense of Article XVI of GATT 1994;

and

(b) a benefit is thereby conferred."

The definitions presented so far underscore the considerable variation in the scope of what constitutes a subsidy. Some definitions are broad, incorporating subsidies that result from budgetary expenditures or foregone revenue, while other definitions are much narrower, capturing only budgetary expenditures. Some definitions include

both producer and consumer subsidies, while other definitions focus on one or the other. Despite providing its own definition in the ASCM, the WTO (2006) noted in a separate report the difficulty of defining subsidies: “Subsidies defy easy definition. The narrowest definition would not extend beyond budgetary outlays and the broadest might incorporate virtually any government policy resulting in a change in conditions in the market place.”

Given the focus of this dissertation on energy subsidies, I also explore the definitions of energy (or fossil fuel) subsidies specifically. Many of these definitions are provided by intergovernmental organizations (IGOs). The Organisation for Economic Co-operation and Development (OECD, 2013) defines fossil fuel subsidies around budgetary expenditures, excluding subsidies that are provided through foregone government revenues. The Organization of the Petroleum Exporting Countries (OPEC) defines energy subsidies by comparing the domestic price to the production cost only, not international market prices, thereby excluding subsidies based on foregone revenues (IEA et al., 2010). The International Energy Agency (IEA, 2006) provides a comprehensive definition of energy subsidies as “any government action that ... lowers the cost of energy production, raises the price received by energy producers or lowers the price paid by energy consumers.” The World Bank’s Energy Subsidy Reform Assessment Framework (ESRAF) provides a similar definition of energy subsidies as any “deliberate policy action by the government that specifically targets electricity, fuels, or district heating and that results in one or more of the following effects: A | It reduces the net cost of energy purchased. B | It reduces the cost of energy production or delivery. C | It increases the revenues retained by those engaged in energy production and delivery (energy suppliers)” (Kojima, 2017). The IEA’s (2006) and World Bank’s three-pronged definitions of energy subsidies are almost identical, with the World Bank emphasizing the term “deliberate” to exclude broader government actions that are not deliberately targeting the energy sector.

In contrast to some of the other IGOs, the IMF provides several definitions of subsidies, distinguishing between producer and consumer subsidies (Clements et al., 2013). The IMF states that “consumer subsidies arise when the prices paid by consumers, including both firms (intermediate consumption) and households (final consumption), are below supply costs” and that “producer subsidies arise when prices are above this level.” For the former, the IMF distinguishes between pre-tax

and post-tax consumer energy subsidies. According to the IMF, “pre-tax consumer subsidies exist when energy consumers pay prices that are below the costs incurred to supply them with this energy,” while they define post-tax subsidies to encompass both pre-tax subsidies and the absence of taxation to reflect the externalities associated with energy use. Since 2021, the IMF has renamed “pre-tax” subsidies as “explicit” subsidies and “post-tax” subsidies as “implicit” subsidies (Fossil Fuel Subsidy Tracker, 2024). However, this renaming may exacerbate the confusion around subsidy definitions, as others have also used the terms explicit and implicit to distinguish between energy subsidies that require direct expenditure (referred to by others as explicit subsidies) and those that arise because of foregone revenue (referred to by others as implicit subsidies), as discussed by Krane et al. (2020). To avoid confusion, from this point onwards, the terms implicit and explicit are only used to differentiate between subsidies that require direct expenditure and those that result in foregone revenue. For IMF-related subsidy estimates and analyses, the previous terminology of pre-tax and post-tax is retained.

Governments also disagree on which definition of energy subsidies to use. Since the leaders of the Group of 20 (G20) first committed to phasing out inefficient fossil fuel subsidies in 2009 (G20, 2009), their governments have discussed and disagreed on subsidy definitions, as noted in joint reports prepared by the IEA, OECD, and OPEC (IEA et al., 2010; IEA et al., 2011). Koplow (2012) underscored this lack of agreement by synthesizing the definitions chosen by each country. Koplow (2012) noted that the G20 Members “continue to select definitions for what counts as a fossil-fuel subsidy.” For example, the Saudi government stated at the time that “while domestic fossil fuel prices in Saudi Arabia could be below international prices, these prices reflect the country’s comparative advantage in oil production and are above the production costs. Indeed, the Government is not paying any fossil fuels-related subsidy from the treasury. Therefore, Saudi Arabia is not implementing any measures that fit the criteria for inefficient fossil fuel subsidies” (Koplow, 2012). South Korea and Turkey also selected a similar definition of subsidies (Koplow, 2012). Other countries used a broader definition of subsidies instead. Italy, for example, adopted the IEA’s definition, stating that it “considers favorably the International Energy Agency’s (IEA) definition of fossil fuel subsidies” (Koplow, 2012). Other countries, such as Mexico, did not adopt a definition. Instead, Mexico

noted that “it would be necessary for all countries to agree on a uniform methodology for calculating subsidies” (Koplow, 2012).

To conclude, this thesis focuses on the reform of consumer energy subsidies and adopts a definition like that used by the IEA and World Bank, which also makes it similar to the IMF’s pre-tax (now known as explicit) definition. The definition used in this thesis thus states that consumer energy subsidies exist if there is some deliberate government intervention that lowers the price of fuels or electricity paid by consumers, thereby conferring to them an advantage. This thesis thus encompasses consumer energy subsidies (or fossil fuel subsidies) that arise from direct budgetary expenditures and those that represent foregone government revenue. However, it excludes clean energy subsidies that are given to renewable sources of energy.

## **1.2 The Rationale for Introducing Energy Subsidies**

Energy subsidies are economic instruments that are introduced by governments to achieve a certain policy objective, usually some kind of socioeconomic goal.

Examining countries in the Arab world, Fattouh and El-Katiri (2017) observed several common policy objectives, including 1) expanding access to energy, 2) protecting the poor, 3) fostering industrial development, 4) consumption smoothing, 5) avoiding inflationary pressures, and 6) other political reasons. These objectives can be broadly classified into those that support households and those that support industry. Among these policy objectives, most studies highlight the protection of lower-income households as the key policy goal for most energy subsidies (Inchauste and Victor, 2017; Rentschler and Bazilian, 2017a).

For households, fuels and electricity provide essential energy services such as lighting, heating, cooling, and mobility, and consumer energy subsidies help make these essential services affordable, effectively acting as a social safety net (Moerenhout, 2022). As noted by Fattouh and El-Katiri (2017), energy poverty, defined as the lack of household access to modern fuels and electricity, remains a significant challenge in many developing countries. Energy subsidies are a tool that policymakers can use to reduce energy poverty. For example, Hosan et al. (2023) found that energy subsidies in Bangladesh had a significant impact on reducing the level of energy poverty in the country.

Because energy subsidies support households, they have been considered a “cornerstone” of the social contract between citizens and their governments, especially in resource-rich Middle Eastern countries (Hertog, 2017; Moerenhout et al., 2017). Subsidies on fuel and electricity are used to distribute the rents from oil and gas exports to citizens. As noted by Fattouh and El-Katiri (2017), “many citizens in oil and gas producing countries consider low-priced energy as a guaranteed birthright.”

For industry, energy subsidies have traditionally been used to promote the development of nascent industries, particularly energy-intensive ones (Rentschler and Bazilian, 2017a). Moerenhout (2022) has discussed how resource-rich countries have traditionally used their resource endowments to support the growth of energy-intensive industries. For example, in Saudi Arabia, low-cost fuels and feedstocks helped turn Saudi Arabia’s nascent petrochemical sector into a global leader (Matar et al., 2015).

While there may be alternative policy instruments for reducing energy poverty or promoting industrial development, those alternative instruments may not have been considered when the energy subsidies were introduced or may not have been feasible or available (Inchauste and Victor, 2017). Furthermore, policymakers at the time may not have been aware of the fiscal, economic, resource, and environmental costs associated with energy subsidies.

### **1.3 The Consequences of Energy Subsidies and Drivers of Their Reform**

Although energy subsidies can help governments achieve key policy objectives, such as protecting lower-income households, research suggests that they are inefficient due to their high costs (Commander, 2012). This inefficiency has been demonstrated by multiple studies that found that most energy subsidies get captured by higher-income households (Clements et al., 2013). Arze del Granado et al. (2010) found that, on average, the top income quintile of households in developing countries captures six times more fuel subsidies than the bottom quintile. In Saudi Arabia’s Fiscal Balance Program (2016), which introduced the government’s energy price reform initiative, it was noted that “lower income households (approx. ~40% of the population) benefit from only around 30% of energy subsidies.”

The primary costs of energy subsidies can broadly be categorized into fiscal, economic, and environmental costs (Rentschler and Bazilian, 2017a). Estimates of the size or magnitude of energy subsidies provide an indication of the fiscal costs, as energy subsidies are generally defined as transfers from governments to consumers or producers. Clements et al. (2014) estimated pretax subsidies for petroleum products for 176 countries at 492 billion USD in 2009, roughly 0.7% of global GDP and over two percent of total government revenues. Most of this estimate was made up of consumer energy subsidies, with producer subsidies accounting for less than five percent. Clements et al. (2014) also found that Middle Eastern countries accounted for almost half of global energy subsidies. Coady et al. (2017) estimated pre-tax global energy subsidies between 2011 and 2015 to range between roughly 300 and 500 billion USD, with year-to-year variations driven mainly by changes in international fuel prices. The IEA (2023) has also been tracking energy subsidies for years, and its most recent estimate puts global energy subsidies in 2022 at over 1 trillion USD, which they described as “by far the largest annual value ever seen.” When borne by the government, the size or magnitude of the subsidy is equal to the fiscal cost (Davis, 2017). However, the costs of subsidies are not always borne by the government, as other actors in the economy can subsidize each other, such as producers subsidizing consumers (Gooptu, 2019). Nevertheless, even if producers absorb some of the costs, there remains a fiscal cost on the government through lower net profits for producers and thus lower tax revenue from those producers (Davis, 2017).

Historically, high fiscal costs have been the primary drivers of energy subsidy reform (Vagliasindi, 2013; Rentschler and Bazilian, 2017a). For example, in many oil-exporting countries, the collapse in international oil prices in late 2014 and the subsequent decrease in oil revenue for those governments triggered the implementation of energy subsidy reforms to improve the fiscal balance (Fattouh et al., 2016). In many oil-importing countries, reforms were undertaken when the fiscal burden from fuel subsidies became too large, generally during periods of high international oil prices, such as between late 2009 and early 2014 (Vagliasindi, 2013; Kojima, 2016).

The economic costs of energy subsidies have also been found to be very high. Fiscal deficits and public debt, which can arise due to the provision of energy

subsidies, have been shown to depress economic growth. Kumar and Woo (2010) found that “on average, a 10 percentage point increase in the initial debt-to-GDP ratio is associated with a slowdown in annual real per capita GDP growth of around 0.2 percentage points per year.” Plante (2013) studied the macroeconomic effects of providing energy subsidies in oil-importing and oil-exporting countries. For both types of countries, Plante (2013) demonstrated that a subsidy results in welfare losses that increase substantially as the magnitude of the subsidy increases, adding that the “distortion in relative prices is the main reason that aggregate welfare is lower” (Plante, 2013). Furthermore, Plante (2013) elaborated on how providing an energy subsidy “leads households and firms to over-consume oil products, drives up wages in the economy, and increases production in the traded sector. The subsidy also distorts the relative price of non-tradables to tradable goods.” Since the provision of subsidies can strain fiscal budgets, energy subsidies can also crowd out public spending in other essential areas, such as health and education (Rentschler and Bazilian, 2017a). Such an inefficient allocation of public expenditure can further depress economic growth (Clements et al., 2014).

The environmental costs of energy subsidies encompass the damages caused by various environmental externalities associated with fossil fuel consumption. These environmental externalities include CO<sub>2</sub> emissions and air pollution, among other externalities. Davis (2017) estimated the total external damages from gasoline and diesel subsidies globally in 2014 to be 44 billion USD, including 8 billion USD from CO<sub>2</sub> emissions and 7 billion USD from local air pollutants. (The remaining 29 billion USD were due to traffic congestion and road damages, which Davis (2017) also grouped under the umbrella of environmental costs.) Davis (2017) also found that Saudi Arabia, Venezuela, and Iran had the highest external costs from fuel subsidies in 2014. Looking at global energy subsidies, Coady et al. (2017) estimated that removing post-tax energy subsidies in all countries in 2013 could have reduced CO<sub>2</sub> emissions by 21 percent, which “would represent a major step towards the decarbonization ultimately needed to stabilize the global climate system.” As for air pollution, Coady et al. (2015) found an even more dramatic effect, estimating that removing energy subsidies globally in 2013 could have resulted in a 55% reduction in premature air pollution deaths worldwide.

Although environmental concerns have not historically been a key driver of energy subsidy reform, this is expected to change as countries take more ambitious actions to mitigate climate change. To meet the goals of the Paris Agreement (2015), countries will need to implement a portfolio of climate change policies, including energy subsidy reform, which was emphasized by the Glasgow Climate Pact at COP26 (UN Climate Change Conference, 2021).

There have been several other multilateral initiatives that aimed to get countries to reduce or eliminate their energy subsidies. In 2009, G20 leaders committed to “rationalize and phase out over the medium term inefficient fossil fuel subsidies that encourage wasteful consumption” (G20, 2009). However, a recent report by the OECD/IEA (2021), which was prepared for the 2021 G20 summit, highlighted how “G20 country support levels remain unchanged [since 2009] in nominal terms to those of a decade ago, at USD 159.3 billion in 2020 compared to USD 161.8 billion in 2010” despite consistent reaffirmations by G20 countries.

Finally, as with energy subsidies, it is also important to define the term energy subsidy reform. This thesis defines energy subsidy reform as the reduction or removal of energy subsidies. Looked at from another perspective, energy subsidy reform can be defined as an increase in a country’s regulated energy prices that brings them closer to the level they would have been at if those prices were deregulated. Therefore, the terms energy subsidy reform and energy price reform are often used interchangeably (Clements et al., 2013; Coady et al., 2018), as the under-pricing of energy is frequently looked at through the lens of energy subsidies (Kojima, 2016; Coady et al., 2018).

## **1.4 The Challenges to Implementing Energy Subsidy Reforms**

Despite the mounting drivers to implement energy subsidy reform, countries face political challenges in successfully reforming their energy subsidies. As noted by Danise et al. (2010) in their study on China, India, and Russia, “politicians in all three countries have been wary of provoking social unrest by imposing unpopular energy price hikes,” adding that this concern was shared between democratic and non-democratic countries, and between energy exporters and energy importers. Social unrest is not only a politically unwelcome outcome for government leaders, but it can

also entail high private and social costs for economies “due to the destruction of assets and infrastructure, disruption to markets, increases in the risk of investment and the loss of trust between social groups and between citizens and state institutions” (McCulloch et al., 2022).

Attempts at energy subsidy reform continue to be publicly opposed worldwide. In 2022, various governments faced public opposition following their implementation of energy subsidy reforms. Different groups of stakeholders can drive public opposition. Danise et al. (2010) highlighted some examples of key stakeholders, including “farmers and the urban middle class in India; truckers, farmers, fishermen and car owners in China; energy-intensive industries and domestic consumers of gas and district heating in Russia.”

Energy subsidy reform is often opposed because of the harm it causes to the welfare of households in the absence of compensation or mitigation measures. Although energy subsidies are a costly policy instrument for supporting lower-income households, raising energy prices without offering any compensation will have a deleterious effect on households, who will have to contend with higher energy prices and higher prices for other essential goods that use energy as an intermediate input (Fattouh and El-Katiri, 2017). Even alongside a compensation scheme, energy subsidy reform can trigger social unrest, possibly due to lower-income consumers falling through the social safety net (Schaffitzel et al., 2020). It is also possible that compensation schemes are poorly designed. There may also be a lack of trust between citizens and their governments or a lack of public understanding of energy subsidies. In fact, the public's lack of understanding of the costs and inefficiencies of energy subsidies has been highlighted as a principal barrier to energy subsidy reform (Beaton and Lontoh, 2010).

Industry can also oppose energy subsidy reforms. Higher domestic energy prices can adversely affect the profit margins of firms. As noted by Fattouh and El-Katiri (2017), “the industries that are likely to be affected the most are those with high energy intensity, and those that face high competition (such as petrochemicals) and/or price controls (such as electricity) that prevent them from passing on rising costs to final consumers.” Even if policymakers were not worried about industrial opposition, they may be concerned about the negative economic impacts of energy

subsidy reform, which could damage economic output in some countries with export-dependent industries, while also damaging foreign exchange revenues for the government (Sayadi et al., 2023).

In summary, governments would need to overcome political, social, and economic barriers to implement energy subsidy reforms successfully, avoiding negative outcomes like social unrest and being forced to reverse the reform.

## **1.5 A Focus on Saudi Arabia: Background and Context of Energy Subsidies and Their Reform**

Saudi Arabia is a leading player in the global economy and energy markets, as demonstrated by several metrics. Its GDP in 2022 was 1.11 trillion USD, roughly one-fourth of the GDP for the entire Middle East and North Africa (MENA) region (World Bank, 2024a). Saudi Arabia is also a member of G20, an intergovernmental forum for leading developed and developing economies. Moreover, Saudi Arabia is a leading oil and natural gas producer and was the world's top crude oil exporter in 2022 (OEC, 2024). According to OPEC (2024), Saudi Arabia possesses roughly 17% of the world's proven petroleum reserves, which, alongside its production capacity, has made Saudi Arabia a leading player within OPEC (Al-Moneef, 2020). On the consumption side, Saudi Arabia had one of the highest levels of primary energy consumption in the Middle East in 2022, at 271 Mtoe, representing over one-fourth of primary energy consumption for the region (EI, 2024). According to EDGAR (2023), Saudi Arabia's GHG emissions in 2022 totalled 810.5 million tonnes of CO<sub>2</sub> equivalent (MtCO<sub>2</sub>eq), making it the tenth largest emitter globally. Finally, and most importantly for this thesis, Saudi Arabia is often found to have some of the highest energy subsidies globally. The IEA (2023) listed Saudi Arabia as having the fourth largest energy subsidies in 2022, at almost 80 billion USD, putting the country behind Russia, Iran, and China. Similarly, the IMF (2024) estimated Saudi Arabia's pre-tax energy subsidies to be 129.3 billion USD in 2022, listing it as the second highest behind only China.

Saudi Arabia's large energy subsidies have arisen because of the government's regulation of domestic energy prices for decades. The Saudi government noted during its accession to the WTO in 2005 that it was regulating the prices of essential goods, including fuel and electricity, to "secure the needs and welfare of consumers

and preserve important social interests of the Kingdom” (WTO, 2005). For example, gasoline and diesel subsidies supported the mobility of vehicle users across the Kingdom, which is the 14<sup>th</sup> largest country in the world with an area of over two million square kilometres (OPEC, 2024). Oil and natural gas subsidies allowed the national electricity company to deliver electricity to consumers at relatively lower prices, which has supported consumer needs for cooling given Saudi Arabia’s hot climate (KAPSARC, 2020). Furthermore, methane and ethane subsidies have helped Saudi Arabia develop its nascent petrochemical sector into a global leader (Matar et al., 2015).

Nevertheless, energy subsidies have negatively affected Saudi Arabia’s hydrocarbon resources, economy, GHG emissions, and fiscal balance. Between 1972 and 2022, Saudi Arabia’s primary energy consumption grew elevenfold, while its energy-related CO<sub>2</sub> emissions grew almost ninefold (EI, 2024).<sup>2</sup> Such rapid growth is not sustainable – whether from the perspective of resource or environmental sustainability. Lahn and Stevens (2011) examined Saudi Arabia’s growing domestic energy consumption and ran simulations that showed that, on its trajectory at the time, Saudi Arabia could “become a net importer of oil by 2038”, which would cause the country to lose one of its primary sources of fiscal revenue, with potentially severely damaging consequences on its economy. With regards to its fiscal balance, the provision of energy subsidies combined with rising domestic energy consumption and falling international oil prices in 2015 contributed to the largest recorded budget deficit in Saudi Arabia’s history – around 100 billion USD in that year (Jadwa Investment, 2015).

The concerns over resource and fiscal sustainability prompted efforts to reform energy subsidies in Saudi Arabia. The first major episode, which occurred at the start of 2016, resulted in substantial increases in fuel, electricity, and water prices for households and industries. The second major episode, which occurred two years later at the start of 2018, targeted a subset of fuels and included vast increases in residential electricity tariffs. Before these two episodes, domestic energy prices in

---

<sup>2</sup> These growth rates are much larger than the less-than-threelfold growth observed in energy consumption and emissions for the world over the same period (EI, 2024).

Saudi Arabia had remained largely fixed in nominal terms for at least the previous decade, if not more, as discussed in more detail in Chapter 3.

Saudi Arabia's efforts to reform its energy subsidies fall under Saudi Vision 2030, a long-term strategy for economic and social transformation that was first launched in 2016 (Saudi Vision 2030, 2016). Saudi Vision 2030 includes around a dozen "Vision Realization Programs," including the Human Capability Development Program, the Privatization Program, the Quality of Life Program, and the Fiscal Sustainability Program, which was formerly called the Fiscal Balance Program (Saudi Vision 2030, 2024). Energy price reform in Saudi Arabia was an initiative that was first launched under the Fiscal Balance Program (2016-2019), reinforcing the widespread perception that fiscal reasons are the primary drivers of energy subsidy reform implementation.

Environmental concerns and Saudi Arabia's public commitments to climate change mitigation are expected to be significant drivers of further energy subsidy reforms in the future. In 2015, Saudi Arabia ratified the Paris Agreement (2015) and submitted its first Nationally Determined Contribution (NDC). NDCs are climate action plans that lie at the heart of the Paris Agreement and capture each country's efforts to reduce GHG emissions and adapt to the impacts of climate change (Kingdom of Saudi Arabia, 2015). In 2021, the Saudi government updated its first NDC and submitted a more ambitious emissions reduction target (Kingdom of Saudi Arabia, 2021). It also committed to achieving net zero GHG emissions by 2060 (Saudi Green Initiative, 2025).

At first glance, it may appear surprising that energy price reform has not been explicitly mentioned even once in Saudi Arabia's current NDC submissions. Studies have demonstrated that energy price reform can deliver crucial GHG emission reductions for the Saudi economy. For example, Durand-Lasserve et al. (2020) showed that full energy price deregulation in Saudi Arabia could reduce carbon dioxide emissions by one-third by 2030 relative to a baseline. Similarly, Gasim et al. (2023) demonstrated that further energy price reforms (beyond those implemented up to 2018) could contribute to achieving one-third of Saudi Arabia's updated NDC emissions target. Given the significant contributions that further energy price reforms would have in helping Saudi Arabia achieve its NDC and net zero targets, the

government will likely need to implement such reforms to meet its climate commitments.

However, the government's apparent averseness to publicly commit to energy price reforms in its NDCs may be driven by the political economy sensitivities associated with energy price reform implementation. The absence of energy price reform in the Saudi NDCs also likely reflects the government's need for flexibility to implement energy price reforms at a time and in a way that aligns best with Saudi Arabia's evolving national circumstances and priorities.

Since energy price reform can contribute to resource, fiscal, and environmental sustainability, thereby helping various policymakers in Saudi Arabia meet their respective policy objectives, the government recently established a cross-cutting high-level committee known as the Energy and Water Price Reforms Executive Committee (Government of the Kingdom of Saudi Arabia, 2025). Although there is limited public information on this committee, it appears to be responsible for overseeing the implementation of energy price reforms, ensuring coordination between relevant ministries and agencies, and ensuring that the reforms are implemented successfully to meet national objectives. It is difficult to gauge how important meeting national climate targets is as a driver of energy subsidy reform implementation for Saudi Arabia and this committee, but it will almost surely grow in importance as Saudi Arabia approaches the target dates for its climate commitments.

In 2022, the Saudi government announced new plans for further energy subsidy reforms (Arab News, 2022). However, Saudi Arabia, like many other countries, faces challenges in implementing those reforms, which led the government to postpone some of its announced plans. Nevertheless, gradual energy subsidy reforms have continued in Saudi Arabia in 2024 and 2025 (Riyad Capital, 2024; Arab News, 2025), and there remains significant scope for further energy subsidy reform (Aljazira Capital, 2025).

## **1.6 Thesis Research Questions and Structure**

This thesis seeks to inform policymakers in Saudi Arabia and support their efforts to reform energy subsidies successfully by answering four crucial research questions. It is structured as follows. Chapter 2 answers the first research question, which asks

how consumers in Saudi Arabia respond to the changes in energy prices that result from energy subsidy reform. An understanding of how energy price changes affect energy consumption is a necessary input for measuring the impacts of subsidy reform. Chapter 3 then answers the second research question, which asks how large the economic, fiscal, and environmental impacts of energy subsidy reform in Saudi Arabia are. Quantifying these impacts and highlighting the benefits is needed to support policymakers in launching such reforms. Quantification also allows policymakers to weigh the benefits of reform against the costs. Chapter 4 answers the third research question, which asks about the lessons that policymakers in Saudi Arabia can learn from the experiences of other countries that have attempted energy subsidy reforms under varying conditions. Chapter 4 thus expands the scope to other countries, taking a qualitative approach. Building on the insights from Chapter 4, Chapter 5 answers the final research question, which asks about how much different national circumstances influence the outcomes of energy subsidy reform. The quantitative analysis in Chapter 5 complements and builds on the qualitative analysis from Chapter 4. Finally, Chapter 6 summarizes all the key insights and concludes.

# Chapter 2: Modelling Energy Demand in Saudi Arabia and Measuring the Price Response

## 2.1. Introduction

As energy subsidy reform is a price-based policy instrument, this chapter seeks to understand the consumer response to changes in energy prices in Saudi Arabia. An understanding of the price response is a prerequisite for measuring the impacts of energy subsidy reform, which are discussed in Chapter 3. Chapter 3 also demonstrates how the size of the price response has important implications on the size of some of the impacts of energy subsidy reform.

Economists generally measure the price response by estimating a demand elasticity, which is a metric that measures how much the demand for a good or service would change in response to a change in a determining variable, which in most economic analyses is either the price or income (Bhattacharyya, 2019). An energy demand price elasticity thus measures how much energy demand changes in response to a change in the energy price. Given that this thesis centers on energy subsidy reform, which operates through price signals, this chapter focuses mainly on estimating energy price elasticities for Saudi Arabia, which are needed in Chapter 3 to measure the impacts of energy subsidy reform.<sup>3</sup>

There are different approaches to estimating energy demand elasticities, and the econometric modelling of energy demand is arguably the most widely used (Bhattacharyya, 2019). Econometric demand modelling is often done with the primary goal of estimating unbiased price and income elasticities (Jones, 1994; Cuddington and Dagher, 2015). The term “unbiased” is often mentioned because there can be different sources of bias that could cause an estimated price elasticity to not be a good reflection of its true value (Wooldridge, 2013), sources of bias that energy demand modelers generally seek to avoid.

---

<sup>3</sup> It is important to note that price and income elasticities of energy demand do find use in a wide range of applications and are not solely used to analyze policy interventions like energy subsidy reform or energy taxation (Dahl, 2012).

Even within the field of econometrics, a wide range of methods have been used to model energy demand and estimate price and income elasticities (Kouris, 1983; Jones, 1994; Agnolucci, 2010; Dilaver, 2012; Agnolucci et al., 2017), and there appears to be a lack of consensus on the best approach to do so (Welsch, 1989; Jones, 1994; Dimitropoulos, 2005). As noted by Welsch (1989), “an issue of particular importance is the treatment of technical progress.” Dimitropoulos (2005) reiterated the need to account for technical progress given that energy demand is a derived demand that is “not demanded for its own sake but for the services it gives in conjunction with energy using appliances and capital stock”. Furthermore, in addition to technical progress, there may be other unobservable factors, such as changes in consumer preferences, that could influence energy demand. As noted by Hunt and Ninomiya (2003), these unobservable factors had been “either (i) ignored or (ii) approximated by a simple linear deterministic trend” in past energy demand studies. Hunt et al. (2003) argued that including a simple linear deterministic time trend when the unobservable factors may be non-linear could lead to “seriously biased” estimates of price and income elasticities. Hunt et al. (2003) argued for the inclusion of stochastic trends in energy demand models to obtain unbiased price and income elasticities, specifically by using Harvey’s (1989) Structural Time Series Model (STSM), which allows users to incorporate stochastic trends in their energy demand equations. Agnolucci (2010) supported Hunt et al.’s (2003) recommendation after comparing several econometric methods, adding that: “as STSMs have not been applied very often in the literature, future studies would benefit from implementing these models.” Given how the STSM can capture the influence of unobservable factors, it is also referred to as the unobserved components model (Harvey et al., 2004; Harvey, 2006).

This chapter employs the STSM to econometrically model energy demand in Saudi Arabia, with the goal of controlling for unobservable exogenous factors and obtaining unbiased price and income elasticities at the most disaggregated level possible. This chapter is structured as follows. Section 2.2 provides background on final energy demand in Saudi Arabia. Section 2.3 summarizes existing studies on energy demand elasticities. Section 2.4 details the STSM methodology, while Section 2.5 presents and discusses the results of the econometric modelling, along with a multitude of econometric tests. Finally, Section 2.6 concludes.

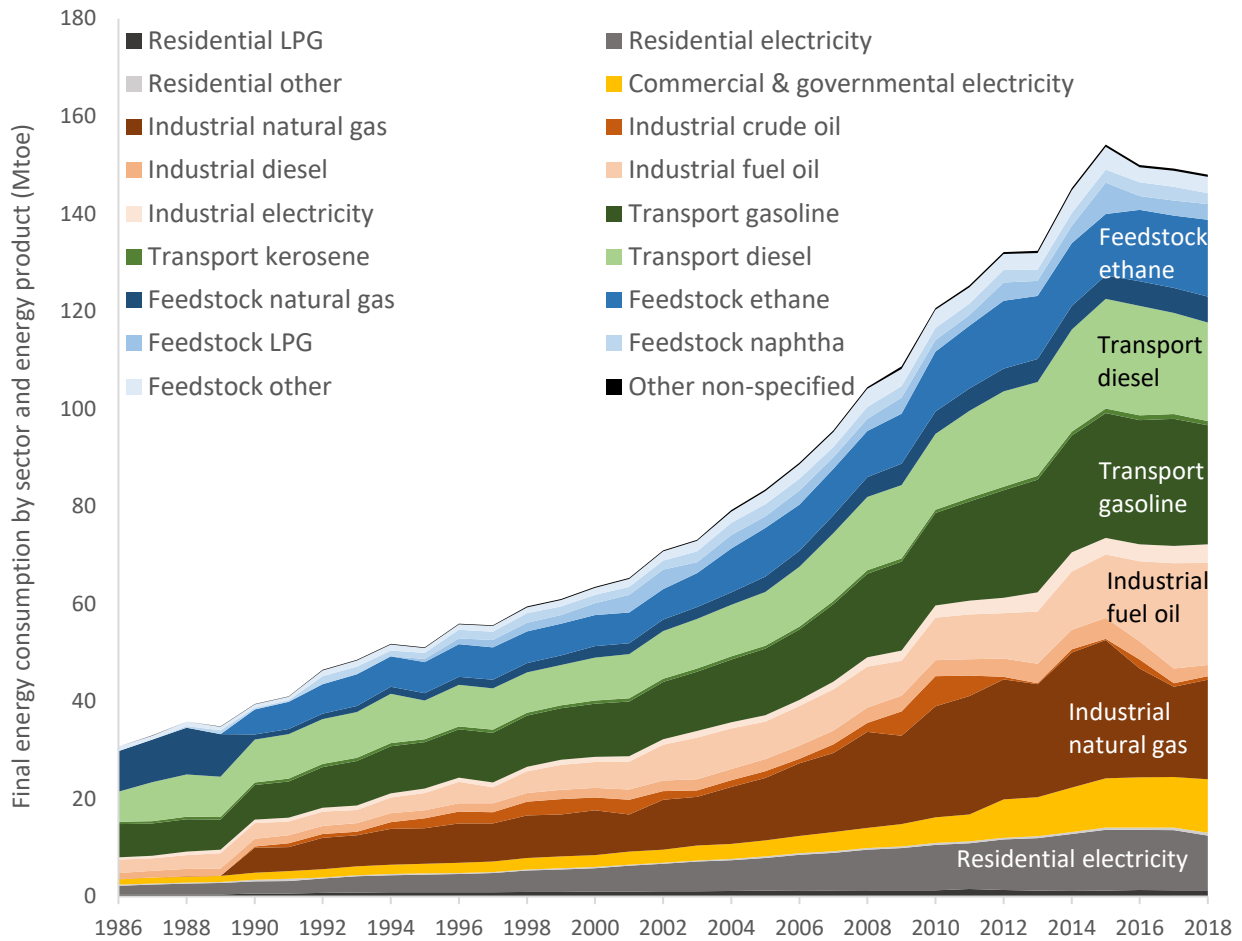
## 2.2. Background on Saudi Final Energy Demand

Final energy consumption in Saudi Arabia has grown rapidly, rising from 30.7 Mtoe in 1986 to 148.0 Mtoe in 2018 (IEA, 2021), as shown in Figure 1, which breaks down final consumption by end-use sector and energy product. Consumption grew rapidly up to 2015 before decreasing between 2015 and 2018, a decline likely driven by the energy efficiency regulations launched in the 2010s, reduced government spending caused by the collapse in international oil prices in late 2014, and energy price reforms (Aldubyan and Gasim, 2021). In 2018, the industrial and transport sectors accounted for the largest shares of final energy consumption, around 33% and 31%, respectively. They were followed by the non-energy use (20%), residential (9%), and commercial and governmental (7%) sectors.<sup>4</sup>

There are differences in the total energy consumption levels of the end-use sectors, each consuming a different set of energy products (IEA, 2021). The Saudi industrial sector consumes natural gas, fuel oil, diesel, crude oil, and electricity to manufacture a wide range of goods, with petrochemicals, cement, and iron and steel manufacturing accounting for the lion's share of the sector's consumption (SEEC, 2021a). The Saudi transport sector consumes three fuels: gasoline, which is used in passenger cars; diesel, which is primarily used in trucks to move freight; and kerosene, which is used for domestic aviation. The non-energy use sector's consumption consists almost entirely of feedstocks such as natural gas (i.e., methane), ethane, LPG, and naphtha, all of which are used by the petrochemical subsector. The petrochemical subsector uses methane to produce fertilizers, while it uses ethane, LPG, and naphtha to produce petrochemicals such as ethylene, propylene, butadiene, and benzene, which are then used to produce chemical, plastic, and rubber products (IHS Markit, 2021). The Saudi residential sector consumes mainly electricity, with small amounts of LPG for cooking, in addition to tiny amounts of kerosene, charcoal, and primary solid biofuels. In contrast to the other sectors, the commercial and governmental sector consumes only electricity.

---

<sup>4</sup> I also refer to the non-energy use sector as the feedstock sector.



**Figure 1** Breakdown of final energy consumption in Saudi Arabia.

Source: IEA (2021).

## 2.3. Related Literature

There exists an extensive array of econometric studies on energy demand. Given the large range of estimated values for price and income elasticities in the literature, several attempts have been made to summarize them into a single value through meta-analysis (Dahl, 1986; Dahl and Sterner, 1991; Epsey, 1998; Epsey and Epsey, 2004; Brons et al., 2008; Havranek et al., 2012; Labandeira et al., 2017). Most of these meta-analyses focused on gasoline or electricity demand. However, Labandeira et al. (2017) extended their meta-analysis to cover most major energy products, estimating the average energy price elasticity in the literature to be around -0.21 in the short run and -0.59 in the long run. This review does not attempt to cover the entire literature on energy demand elasticities but focuses on published studies that estimated price and income elasticities for Saudi Arabia.

In the case of Saudi Arabia, published elasticity estimates exist for some energy products like gasoline and residential electricity, but for many other energy products and sectors there appear to be limited estimates in the literature. Furthermore, many of these limited estimates are outdated, having been obtained using data that only runs up to the 1990s. Table 1 summarizes the results from published studies that found statistically significant price or income elasticities for Saudi Arabia. It shows that gasoline demand in Saudi Arabia is generally both price and income inelastic. Gasoline demand models have been estimated for a range of time horizons using various methods, from simple partial adjustment models estimated by ordinary least squares to cointegration-based error-correction models to STSMs. Electricity demand has also been analyzed with some depth, but existing studies are scattered in terms of sectoral focus, with recent studies focusing on residential electricity demand, which is found to be both price and income inelastic. For all other energy products in Saudi Arabia, there are still many gaps in terms of empirical evidence, so it is difficult to draw conclusions regarding demand responses. In this chapter, I aim to fill these gaps by providing a comprehensive estimation of price and income elasticities for all energy products across all five end-use sectors in Saudi Arabia.

**Table 1** Price and income elasticities from studies that modelled energy demand in Saudi Arabia using econometric methods.

| Study                     | Energy Product          | Estimation Period | Estimation Method | Price Elasticities |                    | Income Elasticities |                    | Notes                                                                                                                                         |
|---------------------------|-------------------------|-------------------|-------------------|--------------------|--------------------|---------------------|--------------------|-----------------------------------------------------------------------------------------------------------------------------------------------|
|                           |                         |                   |                   | SR                 | LR                 | SR                  | LR                 |                                                                                                                                               |
| Al-Sahlawi (1988)         | Gasoline                | 1970-1985         | OLS/PAM           | -0.08              | -0.67              | 0.11                | 0.92               | Given the end of the estimation period, the estimated coefficients may not reflect current demand responses.                                  |
| Al-Sahlawi (1990)         | Total electricity       | 1970-1985         | OLS/PAM           | N/A                | N/A                | 0.37                | 1.21               | May not reflect current demand responses. No price variable included.                                                                         |
| Al-Faris (1992)           | Gasoline                | 1970-1990         | OLS/PAM           | -0.08              | -0.30              | 0.02                | 0.07               | May not reflect current demand responses.                                                                                                     |
| Al-Faris (1997)           | Gasoline                | 1970-1991         | OLS/PAM           | -0.09              | -0.32              | 0.03                | 0.11               | Monetary variables expressed in nominal rather than real terms. No trend included. May not reflect current demand responses.                  |
|                           | LPG                     | 1970-1991         | OLS/PAM           | -0.22              | -0.85              | 0.12                | 0.46               |                                                                                                                                               |
|                           | Jet fuel                | 1970-1991         | OLS/PAM           | -0.20              | -0.43              | 0.26                | 0.57               |                                                                                                                                               |
|                           | Diesel                  | 1970-1991         | OLS/PAM           | -0.37              | -2.47              | 0.18                | 1.20               |                                                                                                                                               |
|                           | Fuel oil                | 1970-1991         | OLS/PAM           | -0.26              | -0.68              | 0.09                | 0.24               |                                                                                                                                               |
| Al-Sahlawi (1997)         | Gasoline                | 1971–1995         | OLS/PAM           | -0.16              | -0.80              | 0.30                | 1.50               | No trend included. May not reflect current demand responses.                                                                                  |
|                           | Diesel                  | 1971–1995         | OLS/PAM           | -0.09              | -0.26              | 0.29                | 0.83               |                                                                                                                                               |
|                           | Jet fuel                | 1971–1995         | OLS/PAM           | -0.51              | -1.00              | 0.45                | 0.88               |                                                                                                                                               |
|                           | Total                   | 1971–1995         | OLS/PAM           | -0.27              | -3.00              | 0.18                | 2.00               |                                                                                                                                               |
| Al-Sahlawi (1999)         | Average electricity     | 1975-1996         | OLS/PAM           | -0.06              | -0.46              | 0.21                | 1.62               | One of the few studies that includes a deterministic linear time trend. May not reflect current demand responses.                             |
|                           | Residential electricity | 1975-1996         | OLS/PAM           | -0.10              | -0.50              | 0.13                | 0.65               |                                                                                                                                               |
|                           | Industrial electricity  | 1975-1996         | OLS/PAM           | N/A                | N/A                | 0.08                | 0.67               |                                                                                                                                               |
| Chakravorty et al. (2000) | Gasoline                | 1972-1992         | OLS/PAM           | -0.08 <sup>n</sup> | -0.52 <sup>n</sup> | 0.10 <sup>n</sup>   | 0.66 <sup>n</sup>  | No trend included. Many of the coefficients with unexpected signs or not statistically significant. May not reflect current demand responses. |
|                           | LPG                     | 1972-1992         | OLS/PAM           | -0.24              | -0.55              | -0.44 <sup>n</sup>  | -1.01 <sup>n</sup> |                                                                                                                                               |
|                           | Jet fuel                | 1972-1992         | OLS/PAM           | 0.36               | 0.71               | 0.37                | 0.74               |                                                                                                                                               |
|                           | Diesel                  | 1972-1992         | OLS/PAM           | -0.39              | -2.63              | 0.01 <sup>n</sup>   | 0.06 <sup>n</sup>  |                                                                                                                                               |
|                           | Fuel oil                | 1972-1992         | OLS/PAM           | -0.12 <sup>n</sup> | -0.35 <sup>n</sup> | 0.50 <sup>n</sup>   | 1.48 <sup>n</sup>  |                                                                                                                                               |

| Study                     | Energy Product                   | Estimation Period | Estimation Method        | Price Elasticities |                   | Income Elasticities |                   | Notes                                                                                                                                                        |
|---------------------------|----------------------------------|-------------------|--------------------------|--------------------|-------------------|---------------------|-------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                           |                                  |                   |                          | SR                 | LR                | SR                  | LR                |                                                                                                                                                              |
| Al-Faris (2002)           | Total electricity                | 1970-1997         | Cointegration ECM        | -0.04              | -1.24             | 0.05                | 1.65              | One of the few studies to include a cross-price variable (the price of LPG). May not reflect current demand responses.                                       |
| Al Yousef (2013)          | Gasoline                         | 1980-2007         | DOLS cointegration       | N/A                | -0.28             | N/A                 | 0.55              | Short-run elasticity estimates were not presented. Price coefficient for diesel was not statistically significant. May not reflect current demand responses. |
|                           | Diesel                           | 1980-2007         | DOLS cointegration       | N/A                | 0.13 <sup>n</sup> | N/A                 | 0.35              |                                                                                                                                                              |
|                           | Kerosene                         | 1980-2007         | DOLS cointegration       | N/A                | -0.96             | N/A                 | 1.54              |                                                                                                                                                              |
|                           | Total                            | 1980-2007         | DOLS cointegration       | N/A                | N/A               | N/A                 | 0.58              |                                                                                                                                                              |
| Atalla and Hunt (2016)    | Residential electricity          | 1985-2012         | STSM                     | -0.16              | -0.16             | N/A                 | 0.48              | The final model for Saudi Arabia does not pass serial correlation test.                                                                                      |
| Atalla et al. (2018)      | Gasoline                         | 1981-2015         | STSM                     | -0.10              | -0.15             | N/A                 | 0.15              | Their results using real GDP per capita as the income variable are presented here.                                                                           |
| Mikayilov et al. (2020a)  | Gasoline                         | 1980-2017         | TVC                      | -0.13              | -0.05 to -0.31    | N/A                 | smaller than 0.15 | Elasticities grew larger towards the end of the period, during which price reforms were implemented.                                                         |
| Alarenan et al. (2020)    | Industrial total energy          | 1986-2016         | STSM                     | -0.18              | -0.34             | 0.60                | 0.60              | Estimation period incorporates only one wave of price reform.                                                                                                |
| Mikayilov et al. (2020b)  | Regional total electricity       | 1990-2016         | Cointegration techniques | -0.01 to -0.27     | -0.06 to -0.63    | 0.05 to 0.47        | 0.10 to 0.93      | Models estimated for four regions of KSA.                                                                                                                    |
| Mikayilov et al. (2020c)  | Regional residential electricity | 1990-2018         | STSM                     | -0.10 to -0.15     | -0.20 to -0.46    | 0.14 to 0.43        | 0.27 to 1.02      | Models estimated for four regions of KSA.                                                                                                                    |
| Aldubyan and Gasim (2021) | Gasoline                         | 1981-2018         | STSM                     | -0.09              | -0.13             | 0.10                | 0.15              | Estimation period incorporates both waves of price reform.                                                                                                   |
|                           | Residential electricity          | 1985-2018         | STSM                     | -0.09              | -0.09             | 0.22                | 0.22              |                                                                                                                                                              |

Notes: The superscript *n* is used to denote estimated elasticities that were not statistically significant. Abbreviations: DOLS = Dynamic Ordinary Least Squares; ECM = Error-Correction Model; LPG = Liquefied Petroleum Gases; LR = Long Run; OLS = Ordinary Least Squares; PAM = Partial Adjustment Model; SR = Short Run; STSM = Structural Time Series Model; TVC = Time-Varying Coefficient

## 2.4 Methods and Data

### 2.4.1 Econometric method

The STSM, also known as the unobserved components model, is a state space model that allows users to model a dependent variable as the sum of multiple components. This thesis focuses on modelling energy demand as the dependent variable. Energy demand, denoted by  $E_t$  or a lower-case  $e_t$  if taking the natural log, where the subscript  $t$  denotes the year, can be modelled using either a univariate or multivariate STSM approach (Harvey, 1989).

With the univariate approach, energy demand can be modelled as follows:

$$e_t = \mu_t + \varepsilon_t, \quad \varepsilon_t \sim NID(0, \sigma_\varepsilon^2) \quad [1]$$

Where  $\mu_t$  is the trend and  $\varepsilon_t$  the irregular component, representing random disturbances with a zero mean and a variance of  $\sigma_\varepsilon^2$ .

If the trend in Equation [1] were assumed to be deterministic, then it could be expressed as follows:

$$\mu_t = \kappa + \rho t, \quad t = 1, 2, \dots, T \quad [2]$$

Where  $\kappa$  is a fixed level and  $\rho$  a fixed slope. As noted by Harvey (1989), this deterministic trend could be converted into a stochastic one by allowing both the level and slope to follow a random walk, but doing so would result in “a somewhat discontinuous pattern for  $\mu_t$ ”; instead, Harvey (1989) proposed formulating the stochastic trend as follows when introducing the STSM:

$$\mu_t = \mu_{t-1} + \rho_{t-1} + \eta_t, \quad \eta_t \sim NID(0, \sigma_\eta^2) \quad [3]$$

$$\rho_t = \rho_{t-1} + \zeta_t, \quad \zeta_t \sim NID(0, \sigma_\zeta^2) \quad [4]$$

Where  $\eta_t$  and  $\zeta_t$  are white-noise disturbance terms with zero means and variances  $\sigma_\eta^2$  and  $\sigma_\zeta^2$ . These variances are also referred to as hyper-parameters. If both variances are found to be zero, the stochastic trend collapses into a deterministic linear trend.

The univariate approach can be extended to include an autoregressive component by adding lags of the energy demand variable to the equation (Harvey, 1989). For example, with two lags, the equation becomes:

$$e_t = \alpha_1 e_{t-1} + \alpha_2 e_{t-2} + \mu_t + \varepsilon_t \quad [5]$$

Interventions, or dummy variables, can also be added to the univariate equation to improve its fit and ensure that it passes all diagnostic tests. These interventions help to maintain the normality of the auxiliary residuals, as they can explain data breaks and major events, trends, or structural changes that influenced energy demand during the estimation period (Harvey and Koopman, 1992). There are different types of interventions that can be added: The irregular intervention has a transient effect on the trend, while the level and slope interventions have permanent effects on the level and slope components of the trend, respectively. Interventions can thus alter the shape of the stochastic trend. Hunt et al. (2003) and Dilaver and Hunt (2011) refer to the stochastic trend in an energy demand equation as the underlying energy demand trend (UEDT), which they define as follows when interventions are added.

$$UEDT_t = \mu_t + \text{irregular interventions} + \text{level interventions} + \text{slope interventions} \quad [6]$$

When no interventions are added, the UEDT is given by  $\mu_t$ , which is the level component.

With a multivariate approach, the energy demand equation can be extended to include explanatory variables like energy prices and income. Using the STSM, I model the demand for each energy product in each end-use sector, or total sectoral energy demand, as a function of the energy price, income, the stochastic trend, and interventions. Furthermore, for certain energy products, I add additional explanatory variables to the models.

I begin with a general unrestricted model (GUM) that is based on the autoregressive distributed lag specification:<sup>5</sup>

---

<sup>5</sup> Like Atalla and Hunt (2016), Atalla et al. (2018), and Aldubyan and Gasim (2021), I use two lags in the GUM given the roughly three-decade time horizon for the energy demand models.

$$e_t^{j,k} = \alpha_1^{j,k} e_{t-1}^{j,k} + \alpha_2^{j,k} e_{t-2}^{j,k} + \beta_0^{j,k} p_t^{j,k} + \beta_1^{j,k} p_{t-1}^{j,k} + \beta_2^{j,k} p_{t-2}^{j,k} + \gamma_0^{j,k} y_t^{j,k} + \gamma_1^{j,k} y_{t-1}^{j,k} + \gamma_2^{j,k} y_{t-2}^{j,k} + \theta_0^{j,k} z_t^{j,k} + \theta_1^{j,k} z_{t-1}^{j,k} + \theta_2^{j,k} z_{t-2}^{j,k} + UEDT_t^{j,k} + \varepsilon_t^{j,k} \quad [7]$$

The variables  $p_t$  and  $y_t$  in Equation [7] denote the natural logarithms of an energy product's real energy price and real income, respectively.  $z_t$  denotes a sector-specific variable, which is included in some models. The superscript  $j$  denotes the energy product, while the superscript  $k$  denotes the end-use sector. The coefficients  $\beta_0$  and  $\gamma_0$  in Equation [7] are respectively the short-run price and income elasticities. The long-run price (B) and income ( $\Gamma$ ) elasticities are calculated as  $B = \frac{\beta_0 + \beta_1 + \beta_2}{1 - \alpha_1 - \alpha_2}$  and  $\Gamma = \frac{\gamma_0 + \gamma_1 + \gamma_2}{1 - \alpha_1 - \alpha_2}$ , and the long-run coefficient for the sector-specific variable ( $\Theta$ ) is also calculated in the same manner.

The additional sector-specific variables include cooling degree days, which capture the impact of warm weather on cooling requirements and electricity use in buildings (EIA, 2025a). This variable was constructed using 18 °C as the base temperature. With this base temperature, cooling degree days reflect the number of degrees that a day's temperature is above 18 °C. For example, if on a certain day the average temperature was 38 °C, then that would produce 20 cooling degree days. This was done for each day of the year to obtain an annual estimate of cooling degree days.

Another important sector-specific variable is the structural factor, which captures the energy intensity (or structure) of manufacturing in Saudi Arabia. The structural factor is measured as the ratio of energy-intensive manufacturing exports (in monetary terms) to total exports (also in monetary terms). It is a ratio that aims to capture how specialized Saudi Arabia is in energy-intensive manufacturing, following the approach used by Alarenan et al. (2020). Alarenan et al. (2020) developed the structural factor by “taking the share of chemical, plastic and rubber, metal, and non-metallic mineral exports in total exports (excluding crude oil).” Since these products are energy intensive, growth in the structural factor should reflect a shift towards energy-intensive exports (and thus energy-intensive manufacturing). Crude oil was excluded from exports to remove the volatility from fluctuations in oil prices. Table 2 lists the variables that were included in each energy demand equation.

I use the general-to-specific approach to obtain final energy demand models, starting from the GUM given by Equation (7). I then test down from the GUM by dropping

insignificant right-hand side variables and adding significant interventions.

Interventions are added based on an analysis of the time series data, residual diagnostic testing, and visual inspection of the residuals. I run this general-to-specific testing down process while monitoring an array of summary statistics and diagnostic tests until a final parsimonious model is found that passes all the tests. When multiple final models are found that pass the tests, the information criterion and prediction error variance are used to select the 'best' model, also referred to as the 'preferred' or 'final' model.

An array of statistics and diagnostic tests are monitored during the general-to-specific testing down procedure. The statistics include the coefficient of determination, the coefficient of determination based on differences, the prediction error variance, and the Akaike information criterion. The diagnostic tests include the heteroscedasticity test, the normality tests for the residuals and auxiliary residuals, and the residual autocorrelation coefficients at multiple lags. The residual diagnostic tests also include the Durbin-Watson statistic, which is relevant for models without a lagged dependent variable, and the Box-Ljung statistic, which is relevant for all models. The diagnostic tests also include the predictive failure test for the last eight years of the estimation period, which checks for model stability and forecasting ability. This thesis sets 10% as the maximum significance level for rejecting the null hypothesis for interventions, diagnostic tests, and estimated coefficients.

I use STAMP 8.3 (Koopman et al., 2007), a package in OxMetrics, to estimate the equations using the Kalman filter and maximum likelihood. As discussed previously, I follow the general-to-specific procedure within STAMP 8.3 until a final parsimonious energy demand model that passes all diagnostic tests is obtained.

### **2.4.2 Time series data**

The annual time series data needed for the econometric modelling were obtained from a multitude of sources. Most time series were obtained for the 1986-2018 period, although data limitations restricted a few time series to the 1990-2018, 1992-2018, or 1994-2018 periods. I obtained the energy demand data from the IEA (2021), real GDP and manufacturing value added data from SAMA (2020), and consumer price index (CPI) data from SAMA (2020), which was used to deflate nominal values. Cooling degree days were constructed using data from the Climate

Change Knowledge Portal (CCKP, 2023), following the approach used by Aldubyan and Gasim (2021). The structural factor was constructed using data from CEIC (2021), following the approach in Alarenan et al. (2020). For certain feedstock sector models, SABIC fertilizer production and real chemical and plastic exports, obtained from CEIC (2021), were used as the economic activity variable.

There is no single public source of historical domestic energy price data for Saudi Arabia. Therefore, I constructed a complete annual energy price dataset by combining a wide range of sources: Aleqt (2015), AlRiyadh (2015), Akhbaar24 (2015), ECRA (2008-2018), ECRA (2013b), ECRA (2019), Matar et al. (2015), Saudi Aramco (2018), SPA (2017), and WTO (2005). As noted in Saudi Arabia's accession to the WTO (2005), the country had been regulating domestic energy prices for decades. In general, energy prices in Saudi Arabia remain fixed in nominal terms, often for years or even decades, until a royal decree is issued to increase or decrease a certain energy price (or a set of energy prices). By reviewing Saudi energy price changes before and after each royal decree, a complete annual time series of energy prices was constructed for the 1986-2018 period.

Table 3 provides the summary statistics for all the model variables.

**Table 2 Independent variables in the GUM for each energy demand equation.**

| <b>End-use sector:<br/>Energy product</b> | <b>Price variable (<math>p_t</math>)</b> | <b>Income or economic activity<br/>variable (<math>y_t</math>)</b> | <b>Additional<br/>variable (<math>z_t</math>)</b> | <b>Estimation<br/>period</b> |
|-------------------------------------------|------------------------------------------|--------------------------------------------------------------------|---------------------------------------------------|------------------------------|
| <b>Transport:</b>                         |                                          |                                                                    |                                                   |                              |
| Gasoline                                  | Real gasoline price                      | Real GDP                                                           |                                                   | 1986-2018                    |
| Diesel                                    | Real diesel for transport price          | Real GDP                                                           |                                                   | 1986-2018                    |
| Kerosene                                  | Real kerosene price                      | Real GDP                                                           |                                                   | 1986-2018                    |
| <b>Residential:</b>                       |                                          |                                                                    |                                                   |                              |
| LPG                                       | Real LPG price                           | Real GDP                                                           |                                                   | 1986-2018                    |
| Electricity                               | Real residential electricity price       | Real GDP                                                           | CDD                                               | 1986-2018                    |
| Other                                     |                                          |                                                                    |                                                   | 1986-2018                    |
| Total                                     | Real weighted average price              | Real GDP                                                           | CDD                                               | 1986-2018                    |
| <b>Commercial &amp; governmental:</b>     |                                          |                                                                    |                                                   |                              |
| Electricity                               | Real weighted average price              | Real GDP                                                           | CDD                                               | 1986-2018                    |
| <b>Industrial:</b>                        |                                          |                                                                    |                                                   |                              |
| Natural gas                               | Real methane price                       | Real MVA                                                           | Structural factor                                 | 1992-2018                    |
| Fuel oil                                  | Real fuel oil price                      | Real MVA                                                           | Structural factor                                 | 1992-2018                    |
| Crude oil                                 | Real crude oil price                     | Real MVA                                                           | Structural factor                                 | 1992-2018                    |
| Diesel                                    | Real diesel for industry price           | Real MVA                                                           | Structural factor                                 | 1992-2018                    |
| Electricity                               | Real industrial electricity price        | Real MVA                                                           | Structural factor                                 | 1992-2018                    |
| Other                                     |                                          |                                                                    |                                                   |                              |
| Total                                     | Real weighted average price              | Real MVA                                                           | Structural factor                                 | 1986-2018                    |
| <b>Feedstock / non-energy use:</b>        |                                          |                                                                    |                                                   |                              |
| Methane                                   | Real methane price                       | SABIC fertilizer production                                        |                                                   | 1990-2018                    |
| Ethane                                    | Real ethane price                        | Real chemical & plastic exports                                    |                                                   | 1992-2018                    |
| LPG and naphtha                           | Real weighted average price              | Real chemical & plastic exports                                    |                                                   | 1993-2018                    |
| Other                                     |                                          |                                                                    |                                                   |                              |
| Total                                     | Real weighted average price              | Real MVA                                                           |                                                   | 1994-2018                    |

*Notes: For certain energy products, the required data was not available, so estimation was not possible. Abbreviations: CDD = cooling degree days; LPG = liquified petroleum gas; MVA= manufacturing value added; GDP = gross domestic product. Since natural gas is mostly made up of methane, the price of methane is the price of natural gas. The use of the word methane helps distinguish it from ethane, which is extracted from natural gas and sold separately as a feedstock at its own separate price.*

**Table 3 Summary statistics for all the model variables.**

| <b>Model variable</b>                                   | <b>Mean</b> | <b>Median</b> | <b>Minimum</b> | <b>Maximum</b> | <b>Standard deviation</b> |
|---------------------------------------------------------|-------------|---------------|----------------|----------------|---------------------------|
| <b>Energy demand variables (ktoe):</b>                  |             |               |                |                |                           |
| Transport gasoline                                      | 13,709      | 11,267        | 6,170          | 26,092         | 6,469                     |
| Transport diesel                                        | 12,286      | 9,827         | 6,161          | 22,529         | 4,961                     |
| Transport kerosene                                      | 655         | 633           | 485            | 948            | 119                       |
| Residential LPG                                         | 962         | 1,025         | 363            | 1,542          | 321                       |
| Residential electricity                                 | 6,096       | 5,274         | 1,454          | 12,426         | 3,519                     |
| Residential total                                       | 7,360       | 6,525         | 2,039          | 14,135         | 3,881                     |
| Commercial & governmental electricity                   | 3,907       | 2,665         | 698            | 10,973         | 3,076                     |
| Industrial natural gas                                  | 14,248      | 11,662        | 4,908          | 28,371         | 7,322                     |
| Industrial fuel oil                                     | 7,115       | 5,692         | 2,421          | 21,563         | 4,866                     |
| Industrial diesel                                       | 2,562       | 2,325         | 1,545          | 4,302          | 829                       |
| Industrial crude oil                                    | 1,832       | 1,420         | 252            | 6,146          | 1,408                     |
| Industrial electricity                                  | 1,840       | 1,263         | 713            | 3,992          | 1,120                     |
| Industrial total                                        | 24,441      | 20,155        | 4,452          | 49,326         | 14,918                    |
| Feedstock methane                                       | 3,462       | 3,142         | 1,053          | 9,576          | 2,053                     |
| Feedstock ethane                                        | 9,247       | 8,990         | 5,096          | 15,759         | 3,286                     |
| Feedstock LPG and naphtha                               | 4,564       | 4,915         | 1,227          | 9,097          | 1,688                     |
| Feedstock total                                         | 19,833      | 20,665        | 10,002         | 31,148         | 6,918                     |
| <b>Energy price variables (units):</b>                  |             |               |                |                |                           |
| Transport gasoline (2010 SR per L)                      | 0.69        | 0.68          | 0.40           | 1.24           | 0.26                      |
| Transport diesel (2010 SR per L)                        | 0.30        | 0.26          | 0.13           | 0.46           | 0.12                      |
| Transport kerosene (2010 SR per L)                      | 0.45        | 0.45          | 0.33           | 0.54           | 0.08                      |
| Residential LPG (2010 SR per L)                         | 0.58        | 0.72          | 0.24           | 0.75           | 0.21                      |
| Residential electricity (2010 SR per kWh)               | 0.09        | 0.09          | 0.07           | 0.16           | 0.02                      |
| Residential total average (2010 SR per kWh)             | 0.09        | 0.09          | 0.06           | 0.15           | 0.02                      |
| Commercial & governmental electricity (2010 SR per kWh) | 0.15        | 0.14          | 0.09           | 0.24           | 0.03                      |
| Industrial natural gas (2010 USD per mmBtu)             | 0.80        | 0.77          | 0.59           | 1.09           | 0.17                      |
| Industrial fuel oil (2010 USD per mmBtu)                | 0.85        | 0.54          | 0.30           | 1.56           | 0.48                      |
| Industrial diesel (2010 USD per mmBtu)                  | 2.04        | 2.06          | 0.93           | 3.01           | 0.76                      |
| Industrial crude oil (2010 USD per mmBtu)               | 0.86        | 0.92          | 0.65           | 0.97           | 0.11                      |
| Industrial electricity (2010 USD per mmBtu)             | 9.49        | 9.77          | 4.59           | 12.24          | 2.41                      |
| Industrial total average (2010 USD per mmBtu)           | 1.49        | 1.51          | 1.04           | 1.97           | 0.26                      |
| Feedstock methane (2010 USD per mmBtu)                  | 0.79        | 0.75          | 0.59           | 1.09           | 0.16                      |
| Feedstock ethane (2010 USD per mmBtu)                   | 0.84        | 0.77          | 0.59           | 1.52           | 0.27                      |
| Feedstock LPG and naphtha (2010 USD per mmBtu)          | 7.02        | 6.28          | 2.54           | 13.38          | 3.62                      |
| Feedstock total average (2010 USD per mmBtu)            | 2.44        | 2.58          | 0.87           | 3.82           | 0.91                      |
| <b>Activity / Income variables (units):</b>             |             |               |                |                |                           |
| Gross domestic product (million 2010 SR)                | 1,612,937   | 1,404,870     | 778,227        | 2,631,091      | 548,665                   |
| Manufacturing value added (million 2010 SR)             | 94,395      | 64,539        | 27,677         | 224,153        | 67,952                    |
| Real chemical exports (million 2010 SR)                 | 52,867      | 38,270        | 9,805          | 127,299        | 40,029                    |
| Fertilizer production (thousand tonnes)                 | 5,229       | 5,297         | 908            | 8,411          | 1,920                     |
| <b>Other (units):</b>                                   |             |               |                |                |                           |
| Cooling degree days (degree days)                       | 2,832.27    | 2,844.87      | 2,460.12       | 3,194.55       | 171.01                    |
| Specialization factor (%)                               | 33          | 32            | 11             | 49             | 9                         |

**Notes:** Abbreviations: L = Liter; ktoe = kilotonnes of oil equivalent; kWh = kilowatt-hour; mmBtu = million British thermal units; SR = Saudi Riyals; USD = United States Dollars.

## 2.5 Econometric Results

### 2.5.1 Overview of results

Final models were obtained using the general-to-specific approach and are shown in Table 4 through Table 8. The tables list the estimated coefficients (i.e., the elasticities), the hyper-parameters that describe the estimated trends, and all the statistically significant interventions that were added to each model. The tables also list all the summary statistics and diagnostic test results that were previously described, demonstrating that all the final models passed all the tests.

The hyper-parameters (or variances of the disturbance terms) are very important because they determine the stochasticity of the components of the STSMs. In each STSM, there are three critical hyper-parameters associated with three key components: the variance of the disturbance for the level component of the trend, the variance of the disturbance for the slope component of the trend, and the variance of the disturbance for the irregular component. These variances can either be positive (therefore introducing stochasticity into each corresponding component) or zero (thereby causing each component to become fixed or deterministic).

The added interventions can be explained in many cases. For some interventions, finding a local, regional, or global event that offers an explanation is relatively straightforward. For example, interventions around 1990-1991 probably capture the impacts of the Gulf War. Interventions around 2007-2009 probably reflect the global financial crisis and its aftermath. Interventions from 2016 onward are probably capturing some of the wider economic and social reforms that were implemented in Saudi Arabia as part of Saudi Vision 2030. A few interventions did not have a clear explanation, but they were likely caused either by smaller local events or breaks in the time series data.

A few interventions were unambiguously connected to breaks in the energy demand time series data that were noted by the IEA (2020). For example, according to the IEA (2020), electricity time series data for Saudi Arabia “were revised from 2012 onwards due to newly available information ... [which] might lead to breaks in time series between 2011 and 2012.” Indeed, I find a level break in 2012 for the commercial and governmental electricity demand model. Similarly, the IEA (2020) states that “new data became available, modifying the estimation of natural gas consumption as feedstock

... [which] may lead to breaks in the time series between 2004 and 2005.” Once again, I find a level break in 2005 for the methane feedstock model. There is a similar explanation for the level break in 1990 in the industrial natural gas demand model, as new data became available, leading to “breaks in time series [that] may occur between 1989 and 1990 for this reason” (IEA, 2020). My review of the IEA’s (2020) metadata notes, along with a thorough inspection of the auxiliary residuals, helped inform my selection of interventions in the general-to-specific process.

The results in Table 4 through Table 8, and the discussions in the subsequent subsections, are organized by end-use sector. For sectors such as transport, in which final models were obtained for each energy product consumed, no total (or aggregate) sectoral energy demand model was estimated. However, for sectors such as industry with missing models for at least one energy product, a total sectoral energy demand model was estimated and discussed.

With the STSM approach, stationarity and cointegration tests are not needed and are generally not performed (Hunt et al., 2003). There have also been criticisms of unit root tests and cointegration methods because of their poor statistical properties (Harvey, 1997; Hunt et al., 2003). Nevertheless, stationarity and cointegration tests were conducted for this analysis and can be found in Appendix A, which demonstrates cointegration for all the energy demand equations, with only the industrial diesel equation having an indeterminate result.

Table 9 summarizes the estimated elasticities and trends from all the final models, revealing that the demand for almost all energy products in Saudi Arabia is price and income inelastic, with only industrial natural gas and electricity having income elasticities larger than one. Table 9 also highlights the extensive variation in elasticities across sectors and energy products within Saudi Arabia. This heterogeneity underscores the importance of using sector- and product-specific elasticity values and not assuming that elasticities are similar across energy products in the same country. My estimated long-run price elasticities vary between -0.05 and -0.60, while the long-run income elasticities vary between 0.14 and 1.27. Since Labandeira et al. (2017) estimated the average long-run energy price elasticity globally using meta-analysis to be -0.596, my results suggest that energy demand in Saudi Arabia is generally more price inelastic than the global average.

Table 9 also reveals the nature of the trends estimated using the STSM, demonstrating that the trends are stochastic in most cases, supporting Hunt et al.'s (2003) recommendation to use STSMs to obtain unbiased elasticity estimates. Industrial natural gas and total feedstock are the only two energy demand models for which I found deterministic linear trends, although there are a few energy products where the trends exhibited weak stochasticity, so the use of a deterministic trend in their modelling may be an adequate approximation.

**Table 4** Final models estimated for the transport sector.

The \*, \*\*, and \*\*\* denote statistical significance at the 10%, 5%, and 1% levels, respectively.

| <b>Transport sector demand models:</b> | <b>Transport gasoline demand</b>                    | <b>Transport diesel demand</b>                                                | <b>Transport kerosene demand</b> |
|----------------------------------------|-----------------------------------------------------|-------------------------------------------------------------------------------|----------------------------------|
| <b>Estimated Coefficients</b>          | (Standard errors in parentheses)                    | (Standard errors in parentheses)                                              | (Standard errors in parentheses) |
| $\alpha_1$ (demand lag 1)              | 0.264** (0.096)                                     |                                                                               |                                  |
| $\alpha_2$ (demand lag 2)              |                                                     | -0.410*** (0.095)                                                             |                                  |
| $\beta_0$ (contemporaneous price)      | -0.120*** (0.013)                                   | -0.269*** (0.026)                                                             | -0.189** (0.091)                 |
| $\beta_1$ (price lag 1)                |                                                     |                                                                               |                                  |
| $\beta_2$ (price lag 2)                |                                                     | -0.138*** (0.032)                                                             |                                  |
| $\gamma_0$ (contemporaneous activity)  | 0.174*** (0.061)                                    | 0.500*** (0.153)                                                              | 0.379** (0.150)                  |
| $\gamma_1$ (activity lag 1)            | 0.185** (0.068)                                     |                                                                               |                                  |
| $\gamma_2$ (activity lag 2)            |                                                     |                                                                               |                                  |
| <b>Derived Long-Run Coefficients</b>   |                                                     |                                                                               |                                  |
| Price                                  | -0.163                                              | -0.289                                                                        | -0.189                           |
| Income                                 | 0.488                                               | 0.355                                                                         | 0.379                            |
| <b>Hyper-Parameters</b>                |                                                     |                                                                               |                                  |
| Level variance                         | 0.000171228                                         | 0.000730446                                                                   | 0.00102849                       |
| Slope variance                         | 0.00000923                                          | 0.000000                                                                      | 0.000000                         |
| Irregular variance                     | 0.000000                                            | 4.01464e-05                                                                   | 0.000359638                      |
| <b>Interventions</b>                   | IRR1987**<br>IRR1988***<br>SLP1989***<br>IRR1990*** | IRR1987***<br>SLP1989*<br>LVL1991***<br>IRR2002**<br>LVL2016***<br>LVL2017*** | IRR1995*<br>LVL2015***           |
| <b>Goodness-of-Fit</b>                 |                                                     |                                                                               |                                  |
| Prediction error variance PEV          | 0.00015045                                          | 0.00051478                                                                    | 0.001367                         |
| Akaike information criterion AIC       | -8.1352                                             | -6.7839                                                                       | -6.1709                          |
| R-squared $R^2$                        | 0.99949                                             | 0.99765                                                                       | 0.95984                          |
| Adjusted R-squared $R_{diff}^2$        | 0.94809                                             | 0.94786                                                                       | 0.57174                          |
| <b>Residual Diagnostics</b>            |                                                     |                                                                               |                                  |
| Standard Error                         | 0.01227                                             | 0.02269                                                                       | 0.03697                          |
| Normality                              | 0.34707                                             | 1.0207                                                                        | 2.4175                           |
| Heteroskedasticity $H(h)$              | $H_{(7)} = 1.6$                                     | $H_{(7)} = 0.88384$                                                           | $H_{(9)} = 2.1992$               |
| Autocorrelation $r(1)$                 | -0.03562                                            | -0.043712                                                                     | -0.093739                        |
| Autocorrelation $r(2)$                 | -0.20569                                            | -0.11466                                                                      | 0.10355                          |
| Autocorrelation $r(3)$                 | -0.074176                                           | 0.033184                                                                      | -0.024939                        |
| Durbin-Watson DW                       | 1.7946                                              | 1.8129                                                                        | 1.8587                           |
| Box-Ljung $Q(p, d)$                    | $\chi^2_3 = 1.5859$                                 | $\chi^2_3 = 0.83163$                                                          | $\chi^2_4 = 1.8486$              |
| Autocorrelation $r(p)$                 | $r(5) = -0.079522$                                  | $r(5) = -0.01806$                                                             | $r(6) = -0.10324$                |
| <b>Auxiliary Residual Diagnostics</b>  |                                                     |                                                                               |                                  |
| Normality Test – Irregular             | 0.71115                                             | 0.53692                                                                       | 0.001449                         |
| Normality Test – Level                 | 1.1529                                              | 0.32616                                                                       | 2.1885                           |
| Normality Test – Slope                 | 1.2099                                              | 1.917                                                                         | 1.5049                           |
| <b>Prediction Failure</b>              | $\chi^2_8 = 10.33179$                               | $\chi^2_6 = 6.62478$                                                          | $\chi^2_7 = 10.22364$            |

**Table 5** Final models estimated for the residential sector.

The \*, \*\*, and \*\*\* denote statistical significance at the 10%, 5%, and 1% levels, respectively.

| <b>Residential sector demand models:</b> | <b>Residential electricity demand</b> | <b>Residential LPG demand</b>    | <b>Total residential energy demand</b> |
|------------------------------------------|---------------------------------------|----------------------------------|----------------------------------------|
| <b>Estimated coefficients</b>            | (Standard errors in parentheses)      | (Standard errors in parentheses) | (Standard errors in parentheses)       |
| $\alpha_1$ (demand lag 1)                |                                       | 0.532*** (0.083)                 |                                        |
| $\alpha_2$ (demand lag 2)                |                                       |                                  |                                        |
| $\beta_0$ (contemporaneous price)        | -0.149*** (0.022)                     |                                  | -0.165*** (0.018)                      |
| $\beta_1$ (price lag 1)                  |                                       |                                  |                                        |
| $\beta_2$ (price lag 2)                  |                                       |                                  |                                        |
| $\gamma_0$ (contemporaneous activity)    | 0.142* (0.070)                        | 0.365*** (0.102)                 | 0.375** (0.068)                        |
| $\gamma_1$ (activity lag 1)              | 0.115* (0.061)                        |                                  |                                        |
| $\gamma_2$ (activity lag 2)              |                                       |                                  |                                        |
| $\delta_0$ (contemporaneous CDD)         | 0.447*** (0.060)                      | N/A                              | 0.398*** (0.073)                       |
| $\delta_1$ (CDD lag 1)                   |                                       | N/A                              |                                        |
| $\delta_2$ (CDD lag 2)                   |                                       | N/A                              |                                        |
| <b>Derived Long-Run Coefficients</b>     |                                       |                                  |                                        |
| Price                                    | -0.149                                | 0.000                            | -0.165                                 |
| Income                                   | 0.257                                 | 0.780                            | 0.375                                  |
| <b>Hyper-Parameters</b>                  |                                       |                                  |                                        |
| Level                                    | 0.000193131                           | 0.000646886                      | 1.52872e-05                            |
| Slope                                    | 4.50501e-05                           | 2.59019e-05                      | 1.28450e-05                            |
| Irregular                                | 0.000000                              | 4.01654e-05                      | 0.000112423                            |
| <b>Interventions</b>                     |                                       |                                  |                                        |
| IRR = Irregular                          | LVL1987***                            | IRR1990***                       | LVL1987**                              |
| LVL = Level                              | IRR1991***                            | LVL1992***                       | IRR1995***                             |
| SLP = Slope                              | IRR1995***                            | IRR2006***                       | SLP2003**                              |
|                                          |                                       | IRR2011***                       |                                        |
|                                          |                                       | LVL2015***                       |                                        |
|                                          |                                       | IRR2017**                        |                                        |
| <b>Goodness-of-Fit</b>                   |                                       |                                  |                                        |
| Prediction error variance PEV            | 0.00022663                            | 0.00061581                       | 0.00021119                             |
| Akaike information criterion AIC         | -7.7861                               | -6.7259                          | -7.9173                                |
| R-squared $R^2$                          | 0.99953                               | 0.99671                          | 0.99944                                |
| Adjusted R-squared $R_{diff}^2$          | 0.9152                                | 0.93914                          | 0.88989                                |
| <b>Residual Diagnostics</b>              |                                       |                                  |                                        |
| Standard Error                           | 0.01505                               | 0.02482                          | 0.01453                                |
| Normality                                | 2.1676                                | 0.29827                          | 1.2143                                 |
| Heteroskedasticity $H(h)$                | $H_{(8)} = 2.3235$                    | $H_{(7)} = 1.1294$               | $H_{(8)} = 1.7947$                     |
| Autocorrelation $r(1)$                   | 0.092871                              | -0.13218                         | 0.15673                                |
| Autocorrelation $r(2)$                   | -0.079143                             | 0.025201                         | -0.05731                               |
| Autocorrelation $r(3)$                   | 0.029468                              | -0.15194                         | 0.044227                               |
| Durbin-Watson DW                         | 1.7352                                | 2.2223                           | 1.6599                                 |
| Box-Ljung $Q(p, d)$                      | $\chi^2_3 = 2.3959$                   | $\chi^2_3 = 2.7441$              | $\chi^2_4 = 1.4879$                    |
| Autocorrelation $r(p)$                   | $r(5) = -0.065127$                    | $r(5) = -0.068708$               | $r(6) = 0.12683$                       |
| <b>Auxiliary Residual Diagnostics</b>    |                                       |                                  |                                        |
| Normality Test – Irregular               | 0.44957                               | 0.72239                          | 0.10314                                |
| Normality Test – Level                   | 1.167                                 | 2.1828                           | 2.8472                                 |
| Normality Test – Slope                   | 2.9299                                | 1.3208                           | 1.7444                                 |
| <b>Prediction Failure</b>                | $\chi^2_8 = 10.81202$                 | $\chi^2_5 = 7.32779$             | $\chi^2_8 = 5.61675$                   |

**Table 6** Final model estimated for the commercial & governmental sector.  
The \*, \*\*, and \*\*\* denote statistical significance at the 10%, 5%, and 1% levels, respectively.

| <b>Commercial &amp; governmental electricity demand model</b> |                                  |
|---------------------------------------------------------------|----------------------------------|
| <b>Estimated coefficients</b>                                 | (Standard errors in parentheses) |
| $\alpha_1$ (demand lag 1)                                     | -0.140*** (0.042)                |
| $\alpha_2$ (demand lag 2)                                     | -0.290*** (0.030)                |
| $\beta_0$ (contemporaneous price)                             |                                  |
| $\beta_1$ (price lag 1)                                       | -0.112*** (0.026)                |
| $\beta_2$ (price lag 2)                                       |                                  |
| $\gamma_0$ (contemporaneous activity)                         | 0.381*** (0.074)                 |
| $\gamma_1$ (activity lag 1)                                   | 0.238*** (0.072)                 |
| $\gamma_2$ (activity lag 2)                                   |                                  |
| $\delta_0$ (contemporaneous CDD)                              | 0.326**** (0.058)                |
| $\delta_1$ (CDD lag 1)                                        |                                  |
| $\delta_2$ (CDD lag 2)                                        |                                  |
| <b>Derived Long-Run Coefficients</b>                          |                                  |
| Price                                                         | -0.078                           |
| Income                                                        | 0.433                            |
| <b>Hyper-Parameters</b>                                       |                                  |
| Level                                                         | 0.000000                         |
| Slope                                                         | 0.000229903                      |
| Irregular                                                     | 1.27186e-05                      |
| <b>Interventions</b>                                          |                                  |
| IRR = Irregular                                               | IRR1991***                       |
| LVL = Level                                                   | IRR2001***                       |
| SLP = Slope                                                   | IRR2003***                       |
|                                                               | IRR2007****                      |
|                                                               | LVL2012***                       |
|                                                               | LVL2014***                       |
| <b>Goodness-of-Fit</b>                                        |                                  |
| Prediction error variance PEV                                 | 0.00017139                       |
| Akaike information criterion AIC                              | -7.7625                          |
| R-squared $R^2$                                               | 0.9998                           |
| Adjusted R-squared $R_{diff}^2$                               | 0.97798                          |
| <b>Residual Diagnostics</b>                                   |                                  |
| Standard Error                                                | 0.01309                          |
| Normality                                                     | 0.091103                         |
| Heteroskedasticity $H(h)$                                     | $H_{(6)} = 0.7939$               |
| Autocorrelation $r(1)$                                        | 0.21429                          |
| Autocorrelation $r(2)$                                        | 0.1796                           |
| Autocorrelation $r(3)$                                        | -0.10262                         |
| Durbin-Watson DW                                              | 1.422                            |
| Box-Ljung $Q(p, d)$                                           | $\chi_3^2 = 2.4144$              |
| Autocorrelation $r(p)$                                        | $r(5) = -0.028342$               |
| <b>Auxiliary Residual Diagnostics</b>                         |                                  |
| Normality Test – Irregular                                    | 1.0125                           |
| Normality Test – Level                                        | 0.27226                          |
| Normality Test – Slope                                        | 0.0060263                        |
| <b>Prediction Failure</b>                                     |                                  |
|                                                               | $\chi_6^2 = 6.91755$             |

**Table 7** Final models estimated for the industrial sector.

The \*, \*\*, and \*\*\* denote statistical significance at the 10%, 5%, and 1% levels, respectively.

| <b>Industrial sector demand models:</b> | <b>Industrial natural gas demand</b> | <b>Industrial diesel demand</b>  | <b>Industrial electricity demand</b> | <b>Total industrial energy demand</b> |
|-----------------------------------------|--------------------------------------|----------------------------------|--------------------------------------|---------------------------------------|
| <b>Estimated coefficients</b>           | (Standard errors in parentheses)     | (Standard errors in parentheses) | (Standard errors in parentheses)     | (Standard errors in parentheses)      |
| $\alpha_1$ (demand lag 1)               | -0.272*** (0.058)                    |                                  |                                      |                                       |
| $\alpha_2$ (demand lag 2)               |                                      |                                  |                                      |                                       |
| $\beta_0$ (contemporaneous price)       | -0.768*** (0.070)                    | -0.138*** (0.009)                | -0.152** (0.071)                     | -0.144** (0.068)                      |
| $\beta_1$ (price lag 1)                 |                                      |                                  |                                      |                                       |
| $\beta_2$ (price lag 2)                 |                                      |                                  |                                      | -0.159*** (0.054)                     |
| $\gamma_0$ (contemporaneous activity)   | 1.309*** (0.130)                     |                                  |                                      | 0.332* (0.168)                        |
| $\gamma_1$ (activity lag 1)             |                                      | 0.139** (0.064)                  |                                      |                                       |
| $\gamma_2$ (activity lag 2)             |                                      |                                  | 1.268*** (0.270)                     |                                       |
| $\delta_0$ (contemporaneous structure)  |                                      |                                  |                                      | 1.020*** (0.248)                      |
| $\delta_1$ (structure lag 1)            |                                      |                                  |                                      |                                       |
| $\delta_2$ (structure lag 2)            |                                      |                                  |                                      |                                       |
| <b>Derived Long-Run Coefficients</b>    |                                      |                                  |                                      |                                       |
| Price                                   | -0.604                               | -0.138                           | -0.152                               | -0.303                                |
| Income                                  | 1.029                                | 0.139                            | 1.268                                | 0.332                                 |
| <b>Hyper-Parameters</b>                 |                                      |                                  |                                      |                                       |
| Level                                   | 0.000000                             | 1.13280e-05                      | 0.000543088                          | 0.00108129                            |
| Slope                                   | 0.000000                             | 0.000000                         | 7.83709e-05                          | 4.37312e-06                           |
| Irregular                               | 0.000498521                          | 0.000189297                      | 0.00128812                           | 0.000285921                           |
| <b>Interventions</b>                    |                                      |                                  |                                      |                                       |
| IRR = Irregular                         | IRR1994***                           |                                  |                                      | LVL1990***                            |
| LVL = Level                             | IRR1997***                           |                                  |                                      | IRR1996**                             |
| SLP = Slope                             | LVL1998***                           | IRR2011***                       | LVL1998***                           | IRR2001***                            |
|                                         | IRR2001***                           | SLP2016***                       | IRR2003***                           | IRR2012***                            |
|                                         | IRR2013***                           | SLP2017***                       | LVL2006***                           | IRR2013***                            |
|                                         | IRR2016***                           |                                  | LVL2015***                           |                                       |
| <b>Goodness-of-Fit</b>                  |                                      |                                  |                                      |                                       |
| Prediction error variance PEV           | 0.0002957                            | 0.00017902                       | 0.0023429                            | 0.0011374                             |
| Akaike info. criterion AIC              | -7.2373                              | -8.0354                          | -5.3897                              | -6.0518                               |
| R-squared $R^2$                         | 0.99929                              | 0.99855                          | 0.99479                              | 0.99849                               |
| Adjusted R-squared $R_{diff}^2$         | 0.98905                              | 0.98269                          | 0.81109                              | 0.95569                               |
| <b>Residual Diagnostics</b>             |                                      |                                  |                                      |                                       |
| Standard Error                          | 0.01720                              | 0.0133798                        | 0.048403                             | 0.033725                              |
| Normality                               | 0.94323                              | 2.1144                           | 2.2273                               | 1.5924                                |
| Heteroskedasticity $H(h)$               | $H_{(5)} = 2.5471$                   | $H_{(6)} = 0.61066$              | $H_{(6)} = 1.5976$                   | $H_{(7)} = 0.68612$                   |
| Autocorrelation $r(1)$                  | -0.1588                              | -0.20034                         | -0.058133                            | -0.10903                              |
| Autocorrelation $r(2)$                  | 0.017964                             | -0.12891                         | -0.053672                            | 0.12753                               |
| Autocorrelation $r(3)$                  | -0.013737                            | -0.024939                        | -0.059234                            | -0.13652                              |
| Durbin-Watson DW                        | 2.2663                               | 2.3439                           | 1.8266                               | 2.1702                                |
| Box-Ljung $Q(p, d)$                     | $\chi_3^2 = 3.6924$                  | $\chi_3^2 = 1.8166$              | $\chi_3^2 = 1.7085$                  | $\chi_3^2 = 1.3562$                   |
| Autocorrelation $r(p)$                  | $r(5) = 0.073069$                    | $r(5) = -0.10823$                | $r(5) = 0.11732$                     | $r(5) = 0.049089$                     |
| <b>Auxiliary Residual Diagnostics</b>   |                                      |                                  |                                      |                                       |
| Normality Test – Irregular              | 0.50562                              | 1.0075                           | 0.91899                              | 1.6573                                |
| Normality Test – Level                  | 0.34092                              | 1.4673                           | 1.4558                               | 0.79247                               |
| Normality Test – Slope                  | 0.0672                               | 4.5656                           | 0.16777                              | 2.0719                                |
| <b>Prediction Failure</b>               | $\chi_6^2 = 7.38711$                 | $\chi_5^2 = 5.97922$             | $\chi_7^2 = 6.53829$                 | $\chi_6^2 = 6.15378$                  |

**Table 8** Final models estimated for the non-energy use sector.

The \*, \*\*, and \*\*\* denote statistical significance at the 10%, 5%, and 1% levels, respectively.

| Non-energy use sector demand models:          | Natural gas feedstock demand                                                                                | Ethane feedstock demand          | LPG and naphtha feedstock demand | Total feedstock demand                             |
|-----------------------------------------------|-------------------------------------------------------------------------------------------------------------|----------------------------------|----------------------------------|----------------------------------------------------|
| <b>Estimated coefficients</b>                 | (Standard errors in parentheses)                                                                            | (Standard errors in parentheses) | (Standard errors in parentheses) | (Standard errors in parentheses)                   |
| $\alpha_1$ (demand lag 1)                     | 0.084*** (0.010)                                                                                            | 0.732*** (0.191)                 |                                  |                                                    |
| $\alpha_2$ (demand lag 2)                     |                                                                                                             | -0.552*** (0.178)                |                                  | -0.352*** (0.115)                                  |
| $\beta_0$ (contemporaneous price)             |                                                                                                             |                                  | -0.306** (0.142)                 | -0.135** (0.055)                                   |
| $\beta_1$ (price lag 1)                       | -0.049* (0.025)                                                                                             | -0.119* (0.069)                  |                                  |                                                    |
| $\beta_2$ (price lag 2)                       |                                                                                                             |                                  |                                  |                                                    |
| $\gamma_0$ (contemporaneous activity)         |                                                                                                             | 0.167* (0.090)                   |                                  | 0.326*** (0.112)                                   |
| $\gamma_1$ (activity lag 1)                   | 0.236*** (0.039)                                                                                            |                                  | 0.655*** (0.189)                 |                                                    |
| $\gamma_2$ (activity lag 2)                   |                                                                                                             |                                  |                                  |                                                    |
| <b>Derived Long-Run Coefficients</b>          |                                                                                                             |                                  |                                  |                                                    |
| Price                                         | -0.053                                                                                                      | -0.145                           | -0.306                           | -0.100                                             |
| Income                                        | 0.258                                                                                                       | 0.204                            | 0.655                            | 0.241                                              |
| <b>Hyper-Parameters</b>                       |                                                                                                             |                                  |                                  |                                                    |
| Level                                         | 0.000278770                                                                                                 | 0.000000                         | 0.000000                         | 0.000000                                           |
| Slope                                         | 0.000000                                                                                                    | 4.03557e-05                      | 0.00176266                       | 0.000000                                           |
| Irregular                                     | 0.000000                                                                                                    | 0.00291787                       | 0.0140197                        | 0.000555132                                        |
| <b>Interventions</b>                          | IRR1994***<br>LVL1996***<br>IRR2000***<br>LVL2005***<br>IRR2006***<br>IRR2009**<br>IRR2010***<br>LVL2015*** | LVL2016*                         | None                             | IRR2003**<br>SLP2006***<br>IRR2012***<br>LVL2016** |
| IRR = Irregular<br>LVL = Level<br>SLP = Slope |                                                                                                             |                                  |                                  |                                                    |
| <b>Goodness-of-Fit</b>                        |                                                                                                             |                                  |                                  |                                                    |
| Prediction error variance PEV                 | 0.00015384                                                                                                  | 0.0035186                        | 0.027867                         | 0.00035562                                         |
| Akaike information criterion AIC              | -7.8141                                                                                                     | -5.0571                          | -3.1957                          | -7.1416                                            |
| R-squared $R^2$                               | 0.9997                                                                                                      | 0.9765                           | 0.87726                          | 0.99809                                            |
| Adjusted R-squared $R_{diff}^2$               | 0.97193                                                                                                     | 0.52028                          | 0.50366                          | 0.93044                                            |
| <b>Residual Diagnostics</b>                   |                                                                                                             |                                  |                                  |                                                    |
| Standard Error                                | 0.01240                                                                                                     | 0.05932                          | 0.16693                          | 0.01886                                            |
| Normality                                     | 0.7309                                                                                                      | 1.1018                           | 0.56544                          | 0.24039                                            |
| Heteroskedasticity $H(h)$                     | $H(5) = 1.5809$                                                                                             | $H(6) = 1.2865$                  | $H(7) = 0.76989$                 | $H(5) = 1.2855$                                    |
| Autocorrelation $r(1)$                        | 0.10998                                                                                                     | -0.10726                         | -0.11017                         | -0.23982                                           |
| Autocorrelation $r(2)$                        | 0.0091968                                                                                                   | -0.0021095                       | 0.029286                         | 0.10599                                            |
| Autocorrelation $r(3)$                        | -0.0044961                                                                                                  | -0.10916                         | 0.061297                         | -0.2208                                            |
| Durbin-Watson DW                              | 1.3361                                                                                                      | 2.044                            | 2.1047                           | 2.4321                                             |
| Box-Ljung $Q(p, d)$                           | $\chi^2_3 = 0.34861$                                                                                        | $\chi^2_3 = 2.3914$              | $\chi^2_3 = 0.85931$             | $\chi^2_3 = 3.7559$                                |
| Autocorrelation $r(p)$                        | $r(5) = 0.0096217$                                                                                          | $r(5) = 0.2007$                  | $r(5) = 0.10458$                 | $r(5) = 0.16766$                                   |
| <b>Auxiliary Residual Diagnostics</b>         |                                                                                                             |                                  |                                  |                                                    |
| Normality Test – Irregular                    | 3.4967                                                                                                      | 1.7232                           | 0.5072                           | 0.81141                                            |
| Normality Test – Level                        | 0.27462                                                                                                     | 0.85327                          | 0.49638                          | 0.077568                                           |
| Normality Test – Slope                        | 0.63793                                                                                                     | 1.0438                           | 1.2511                           | 0.32189                                            |
| <b>Prediction Failure</b>                     | $\chi^2_7 = 10.96511$                                                                                       | $\chi^2_7 = 6.76170$             | $\chi^2_8 = 7.43491$             | $\chi^2_6 = 8.34220$                               |

**Table 9** A summary of the estimated coefficients and the types of estimated trends for each final model.

| End-use sector: energy product        | Price     |          | Income    |          | Trend |       |
|---------------------------------------|-----------|----------|-----------|----------|-------|-------|
|                                       | Short run | Long run | Short run | Long run | Level | Slope |
| <b>Transport:</b>                     |           |          |           |          |       |       |
| Gasoline                              | -0.12     | -0.16    | 0.17      | 0.49     | S     | D     |
| Diesel                                | -0.27     | -0.29    | 0.50      | 0.36     | S     | D     |
| Kerosene                              | -0.19     | -0.19    | 0.38      | 0.38     | S     | D     |
| <b>Residential:</b>                   |           |          |           |          |       |       |
| LPG                                   | ---       | ---      | 0.37      | 0.78     | S     | S     |
| Electricity                           | -0.15     | -0.15    | 0.14      | 0.26     | S     | S     |
| Other <sup>N</sup>                    | ---       | ---      | ---       | ---      | ---   | ---   |
| Total                                 | -0.16     | -0.16    | 0.37      | 0.37     | S     | S     |
| <b>Commercial &amp; governmental:</b> |           |          |           |          |       |       |
| Electricity                           | ---       | -0.08    | 0.38      | 0.43     | D     | S     |
| <b>Industrial:</b>                    |           |          |           |          |       |       |
| Natural gas                           | -0.77     | -0.60    | 1.31      | 1.03     | D     | D     |
| Fuel oil <sup>F</sup>                 | ---       | ---      | ---       | ---      | ---   | ---   |
| Crude oil <sup>F</sup>                | ---       | ---      | ---       | ---      | ---   | ---   |
| Diesel                                | -0.14     | -0.14    | ---       | 0.14     | S     | D     |
| Electricity                           | -0.15     | -0.15    | ---       | 1.27     | S     | S     |
| Other <sup>N</sup>                    | ---       | ---      | ---       | ---      | ---   | ---   |
| Total                                 | -0.14     | -0.30    | 0.33      | 0.33     | S     | S     |
| <b>Feedstock / non-energy use:</b>    |           |          |           |          |       |       |
| Methane                               | ---       | -0.05    | ---       | 0.26     | S     | D     |
| Ethane                                | ---       | -0.15    | 0.17      | 0.20     | D     | S     |
| LPG + Naphtha                         | -0.31     | -0.31    | ---       | 0.65     | S     | D     |
| Other <sup>N</sup>                    | ---       | ---      | ---       | ---      | ---   | ---   |
| Total                                 | -0.13     | -0.10    | 0.33      | 0.24     | D     | D     |

<sup>N</sup> No data available for estimation <sup>F</sup> Final models failed diagnostic tests or did not yield statistically significant coefficients

Abbreviations: S = stochastic, D = deterministic, LPG = liquefied petroleum gas.

Comparing my econometric results to previously published studies on Saudi Arabia, my elasticities are somewhat consistent with previous estimates. For example, in the residential electricity sector, I estimate a long-run price elasticity of -0.15, which lies between the estimates of -0.16 by Atalla and Hunt (2016) and -0.09 by Aldubyan and Gasim (2021). However, my estimate is significantly smaller than the estimate of -0.50 by Al-Sahlawi (1999). For gasoline demand in the transport sector, my long-run price elasticity of -0.16 is slightly larger than the estimates of -0.15 by Atalla et al. (2018) and -0.13 by Aldubyan and Gasim (2021), and it lies in the middle of the range (-0.05 to -0.31) estimated by Mikayilov et al. (2020a) using a time-varying coefficient

approach, but is significantly smaller than the estimates of -0.67 and -0.80 by Al-Sahlawi (1988; 1997). For total/aggregate industrial energy demand, my long-run price elasticity of -0.30 is slightly smaller than the estimate of -0.34 by Alarenan et al. (2020). For other energy products and sectors, it is difficult to make meaningful comparisons because of the absence of recent estimates or the aggregation of a single fuel across multiple sectors in previous studies. Finally, it is important to note that it is likely that the bias between my estimates and past estimates is smaller in the case of past studies that included deterministic trends that had adequately captured the shape of the true underlying trend.

## 2.5.2 Transport sector discussion

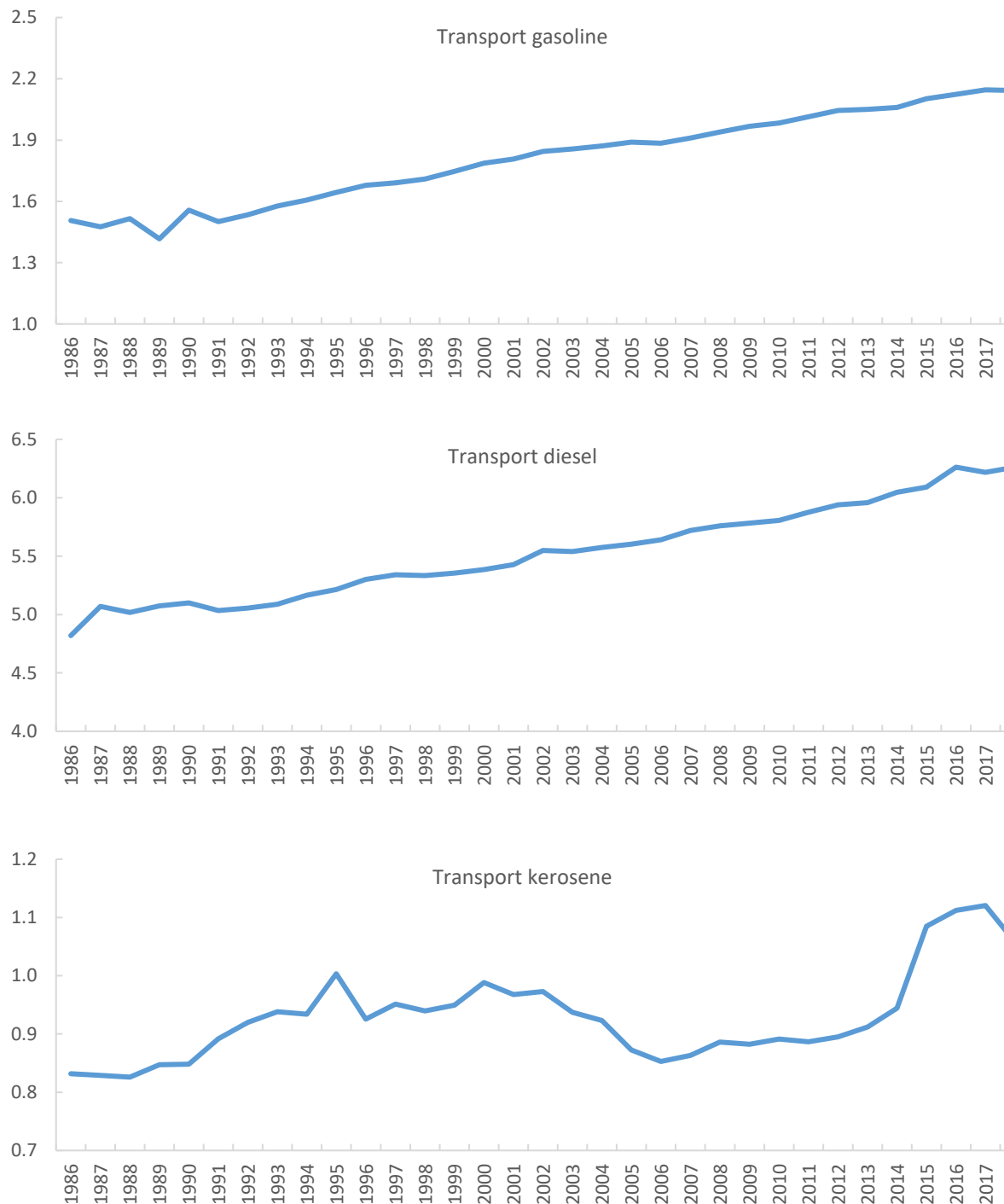
I find gasoline demand to be both price and income inelastic, with estimated short-run elasticities of -0.12 and 0.17, respectively. The corresponding long-run price and income elasticities are estimated to be -0.16 and 0.49, respectively. I also find diesel demand to be price inelastic, with a short-run price elasticity of -0.27 and a long-run price elasticity of -0.29. The results suggest that diesel-consuming firms are more responsive to price changes than gasoline-consuming households. The short-run income elasticity for diesel is also relatively larger, at 0.50, while the long-run income elasticity is only 0.36.<sup>6</sup> Unlike the final models for gasoline and diesel, the final model for kerosene is entirely static, with the price elasticity equal to -0.19 and the income elasticity equal to 0.38.

The estimated UEDTs for the transport sector, shown in Figure 2, are all found to be stochastic and generally upward sloping over the 1986-2018 period, suggesting that exogenous factors, beyond prices and income, increased the demand for gasoline, diesel, and kerosene during this period. In the case of gasoline, it is possible that a shift towards owning larger cars, along with road network expansion and urban sprawl,

---

<sup>6</sup> The relatively smaller long-run income elasticity in the diesel demand model stems from both statistically insignificant coefficients on the lagged income variables and statistically significant negative coefficients on the lagged dependent variables. As noted by Cuddington and Dagher (2015), a short-run price elasticity “may be bigger than, smaller than, or equal to its long-run counterpart” depending on the estimated coefficients. For most goods, long-run elasticities are found to be larger than short-run elasticities as consumers have more time to respond over longer periods. However, Cuddington and Dagher emphasize that it is important not to impose a priori restrictions on the relative magnitudes of short-run and long-run price and income elasticities. They list automobiles as an example of a good with a larger short-run elasticity and discuss cases where short-run income elasticities are higher due to business cycle fluctuations, in contrast to smaller long-run income elasticities that reflect the response to long-term income growth.

led to the upward-sloping UEDT. These same reasons may also explain the upward-sloping UEDT for diesel and its similarity to gasoline. In contrast, the UEDT for kerosene appears erratic, possibly capturing fluctuating preferences regarding air travel and changes in domestic flight ticket pricing policies.



**Figure 2** UEDTs of the final models for the transport sector.

### 2.5.3 Residential sector discussion

I find residential electricity demand to be inelastic to both price and income changes. The estimated residential electricity model has a static price response with a price elasticity of -0.15. I see more dynamics around the income response, with short-run and long-run income elasticities of 0.14 and 0.26, respectively. I also find the elasticity of residential electricity demand with respect to cooling degree days to be 0.45. For the residential LPG model, I do not find a statistically significant price elasticity, a result likely originating from the minimal LPG price variability during the estimation period. In fact, residential LPG was the only fuel unaffected by the price reform in 2016. Nevertheless, I estimate the income elasticity for residential LPG to be 0.36 and 0.69 in the short and long run, respectively. As for the total residential energy demand model, the estimated coefficients are very similar to the residential electricity demand model, which is not surprising given that residential electricity accounts for by far the largest share of total residential energy demand.

The UEDTs for the residential sector models, shown in Figure 3, were all found to be stochastic. The UEDTs for residential electricity demand and total residential energy demand were upward-sloping, likely reflecting an increase in the typical size of a house in Saudi Arabia, along with an increase in the number of installed electrical appliances such as air conditioners and refrigerators. Nevertheless, towards the end of the period (2014-2018), the slopes of both UEDTs flattened out, likely because of the implementation of energy efficiency regulations in the 2010s by the Saudi Energy Efficiency Center (Aldubyan and Gasim, 2021), which was first established in 2010. In contrast, the UEDT for LPG initially increased but decreased from 2000 onwards, a trend possibly reflecting improvements in the efficiency of LPG-based cooking stoves or a shift towards electricity for cooking purposes.



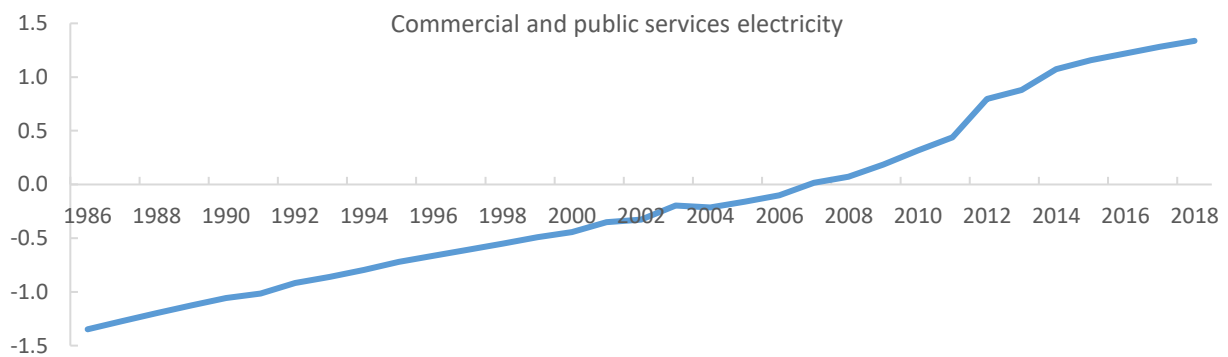
**Figure 3** UEDTs of the final models for the residential sector.

## 2.5.4 Commercial and governmental sector discussion

I find commercial and governmental electricity demand to be strongly price inelastic and somewhat income inelastic in the long run. The final model lacks a short-run price response, but I find the long-run price elasticity to be -0.08. I find more dynamics

around the income response, with an income elasticity of 0.38 in the short run and 0.43 in the long run. The elasticity with respect to cooling degree days is estimated to be 0.33 in the short run.

The UEDT for the final model, shown in Figure 4, is found to be stochastic and upward-sloping. The upward-sloping UEDT may be capturing the use of more lighting or air-conditioning per square meter of floor space in commercial and governmental buildings. The rate of growth accelerates between 2006 and 2012 before slowing down towards the end of the period. This slowdown is also likely the result of energy efficiency policies implemented by the Saudi Energy Efficiency Center to improve building sector efficiency (SEEC, 2021b). (The negative starting point for the UEDT for the commercial and public services sector simply reflects the intercept at the starting period.)



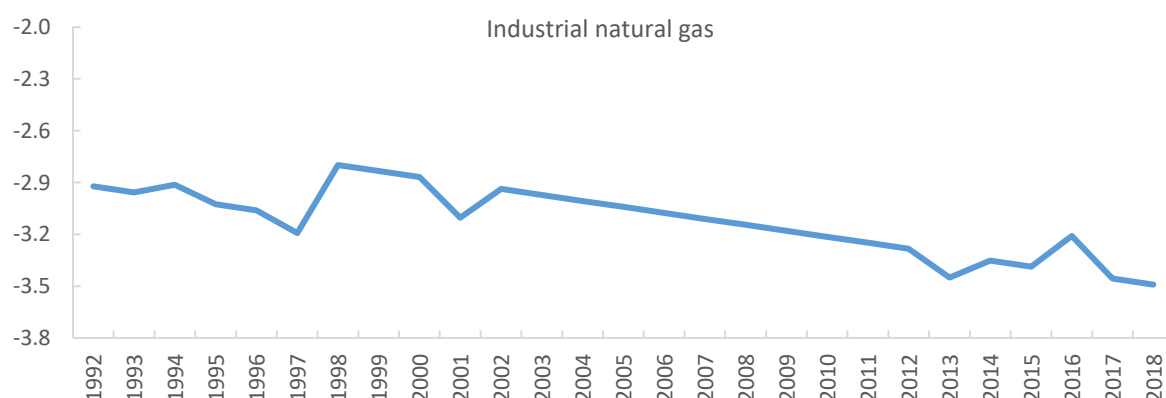
**Figure 4** UEDT of the final model for the commercial and governmental sector.

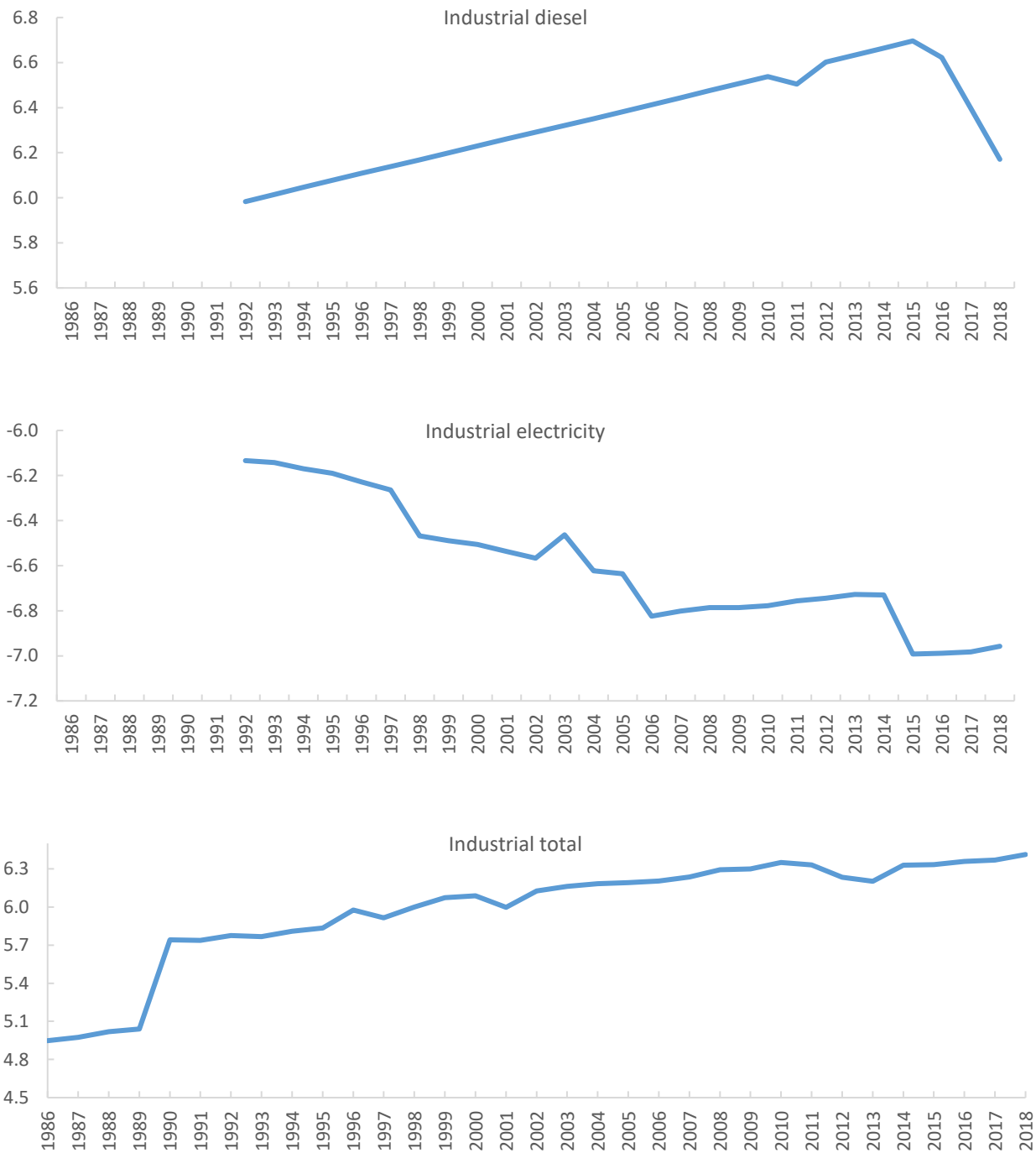
### 2.5.5 Industrial sector discussion

I find relatively more elastic price and income responses for industrial natural gas demand. The price elasticity is estimated to be -0.77 in the short run and -0.60 in the long run due to the negative coefficients on the lagged dependent variables. One possible explanation relates to the nature of the closed natural gas market in Saudi Arabia, which, combined with natural gas subsidies, has caused demand to outstrip supply, forcing the government to ration natural gas consumption (Krane, 2019). It is likely that in the short run, a higher natural gas price causes some firms to reduce their consumption, but in the long run, when the higher price unlocks greater supply, the rationing would not be as stringent and some firms would increase their consumption,

leading to the weaker long-run price response. A similar result is observed in the income response, with short- and long-run income elasticities of 1.31 and 1.03, respectively. For industrial diesel demand, the analysis reveals strongly inelastic price and income responses, with an estimated price elasticity of -0.14 and an income elasticity of 0.14. For the industrial electricity model, I estimate a price elasticity of -0.15 and a large long-run income elasticity of 1.27, with the short-run income elasticity being statistically insignificant. For the total industrial energy demand model, I find demand to be price and income inelastic. The estimated price elasticity is -0.16 in the short run and -0.30 in the long run, while the static income elasticity is estimated to be 0.33. Unsurprisingly, the estimated price elasticity in the total industrial energy demand model lies in between the price elasticities estimated individually for each industrial fuel.

The UEDTs for the final industrial sector models are shown in Figure 5. Excluding natural gas, all UEDTs were found to be stochastic. The UEDTs for total industrial energy demand and diesel demand were generally upward-sloping. The UEDT for total industrial energy demand appears to flatten towards the end of the estimation period, possibly capturing improvements in energy efficiency in the industrial sector (SEEC, 2021a). For diesel, the UEDT becomes sharply downward-sloping from 2015 onwards, a sharp trajectory change that likely reflects government policy to displace diesel use in the industrial sector. In contrast, the UEDTs for natural gas and electricity were generally downward-sloping, potentially capturing exogenous improvements in energy efficiency.





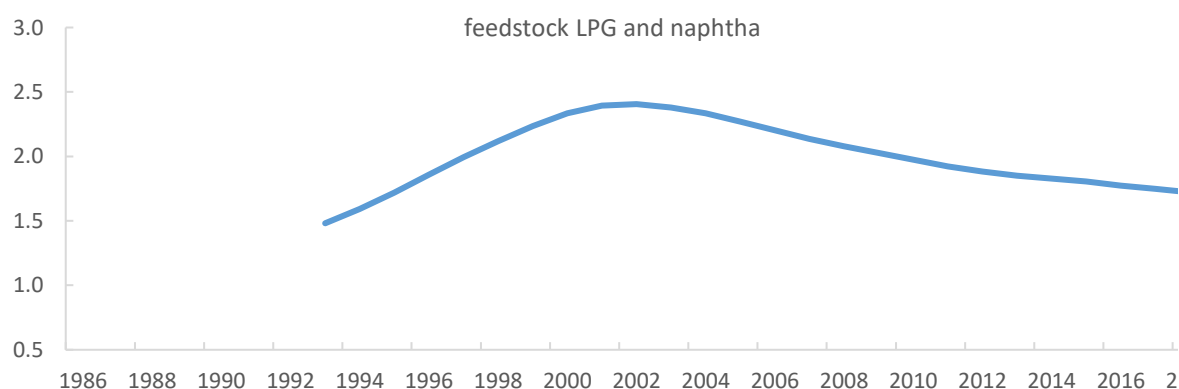
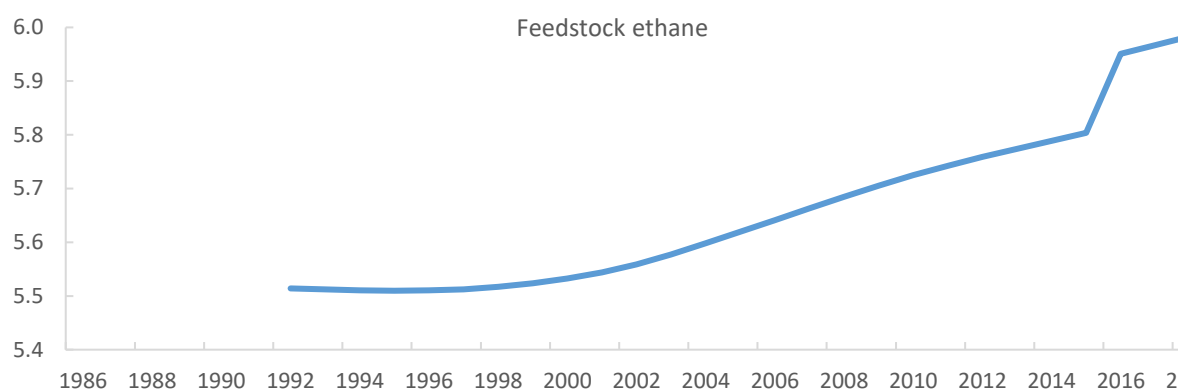
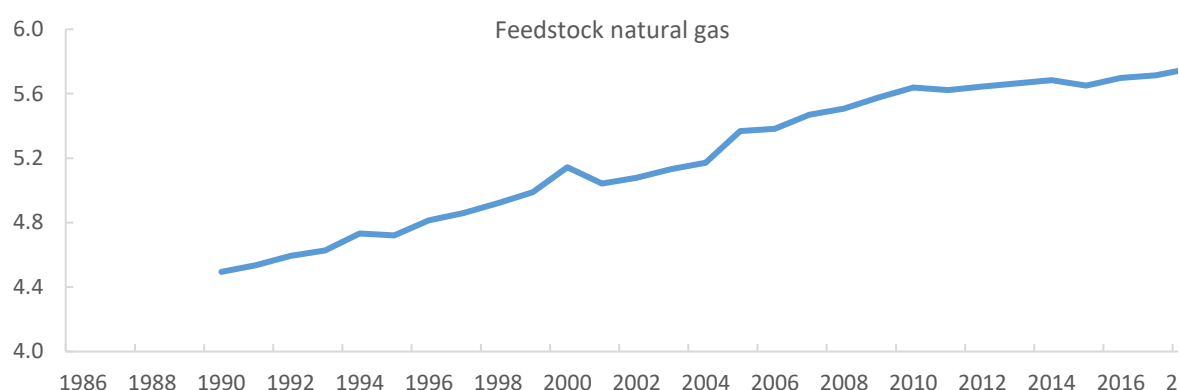
**Figure 5** UEDTs of the final models for the industrial sector.

### 2.5.6 Non-energy use (feedstock) sector discussion

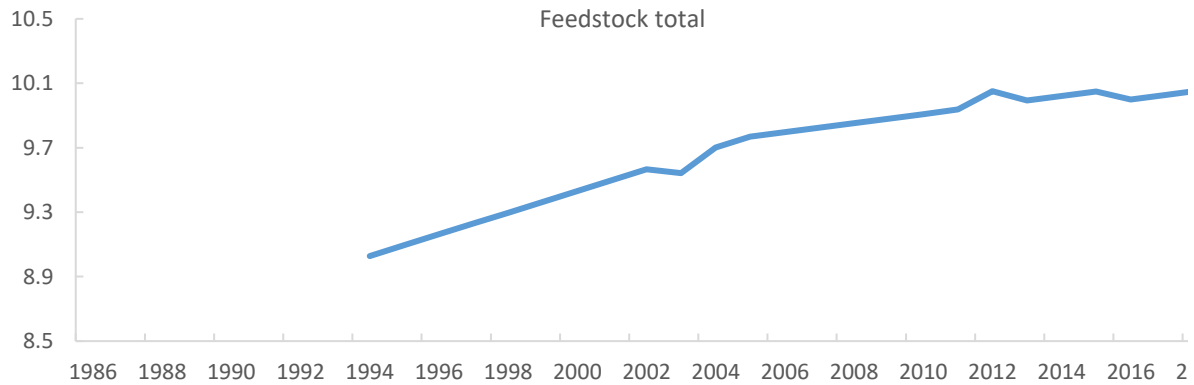
I find natural gas (i.e., methane) feedstock demand to be strongly price inelastic, with long-run price and income elasticities of -0.05 and 0.26, respectively. The small price elasticity likely stems from the lack of feedstock substitutes for methane, which produces a unique set of end-products (mainly fertilizers). For ethane, I find demand to be strongly price and income inelastic. The price elasticity is estimated at -0.12 in the short run and -0.15 in the long run, while the income elasticity is estimated at 0.17 in the short run and 0.20 in the long run. For LPG and naphtha, I obtain a static final model with a price elasticity of -0.31 and an income elasticity of 0.65. This price elasticity is considerably larger than for methane and ethane, a result that may stem from the pricing policy for LPG and naphtha. Unlike other fuels and feedstocks, whose prices are regulated and change infrequently, the prices of LPG and naphtha feedstock have been set as a percentage of the international spot price. Therefore, their prices were relatively much higher on a per-unit of energy basis and a lot more volatile. Petrochemical firms that consume LPG and naphtha may thus be more responsive to energy price changes. As for total feedstock, I find demand to be price- and income inelastic, in line with the estimates for methane and ethane, which account for the largest share of total feedstock demand. The estimated short-run price and income elasticities are -0.13 and 0.33, respectively. Unexpectedly, the long-run price and income elasticities are smaller in magnitude, measuring -0.10 and 0.24, respectively. The rationing of natural gas and ethane feedstocks, as discussed by Krane (2019), may explain the weaker long-run response, in line with the results observed for the rationed use of natural gas as a fuel by the industrial sector.

The UEDTs for the feedstock sector models are shown in Figure 6. Excluding the total model, the estimated UEDTs were stochastic. The UEDTs for total, natural gas, and ethane were found to be upward-sloping. The UEDT for the LPG and naphtha model was upward-sloping up to 2002, at which point it became downward-sloping. As noted previously, LPG and naphtha prices have been substantially higher than methane and ethane prices on a per-unit-of-energy basis, and they have been much more volatile.

The downward-sloping trend for this model may be capturing a shift away from the use of LPG and naphtha as feedstock in the Saudi petrochemical subsector.<sup>7</sup>



<sup>7</sup> I compared the energy demand data obtained from the IEA (2021) with data obtained from JODI (2021) and SAMA (2020). I find the values to be consistent for almost all energy products, except for LPG and naphtha consumed by the petrochemical subsector, suggesting the existence of a potential data issue related to the consumption figures for both fuels.



**Figure 6** UEDTs of the final models for the non-energy use sector.

## 2.6 Conclusion

I estimated 15 energy demand equations for Saudi Arabia, covering all end-use sectors and as many energy products within each sector as possible. My estimates of price and income elasticities cover energy products and sectors for which there were no previous estimates for Saudi Arabia. My results reveal that energy demand is price inelastic for all energy products and income inelastic in all cases except for industrial natural gas and electricity. Nevertheless, I demonstrate the existence of extensive heterogeneity in price and income elasticities across sectors and energy products within Saudi Arabia, with the long-run price elasticity varying between -0.05 and -0.60, and the long-run income elasticity varying between 0.14 and 1.27. This heterogeneity underscores the importance of using sector- and product-specific elasticity values, and not assuming that elasticities are similar across energy products in the same country. Furthermore, by comparing my estimated elasticities to global averages from the literature, I demonstrate that it can be misleading to assume that the consumer response in one country is similar to the global average.

My econometric analysis underscores the importance of incorporating non-linear stochastic trends to obtain unbiased elasticity estimates. I find that for 13 of the 15 energy demand models, the trends are stochastic, with industrial natural gas and total non-energy use being the only two exceptions with deterministic trends. While there are a few energy products whose trends exhibited weak stochasticity, in most cases the non-linearity of the UEDTs is clear. Therefore, the exclusion of trends or

the use of deterministic trends when modelling energy demand in Saudi Arabia may lead to biased elasticity estimates.

My analysis also reveals that most of the UEDTs are upward sloping, reflecting the role of exogenous factors (such as larger houses, more electrical appliances, larger road networks, and urban sprawl) in driving the growth of domestic energy demand and emissions in Saudi Arabia.

The estimated elasticities presented in this chapter are essential inputs to policy discussions and for conducting various analyses on the impacts of policy interventions that affect energy prices. My results also provide a better understanding of how exogenous factors, such as larger houses and longer road networks, helped drive the historical growth in energy demand and emissions in Saudi Arabia, while also allowing for an analysis of how future changes in these variables may affect the trajectories of energy demand and emissions (Chitnis and Hunt, 2012). Finally, and most importantly for this thesis, my estimated elasticities allow for a thorough analysis of the economic, fiscal, and environmental impacts of energy subsidy reform in Saudi Arabia, as discussed in the next chapter.

.

# Chapter 3: The Economic, Environmental, and Fiscal Impacts of Energy Subsidy Reform in Saudi Arabia

## 3.1 Introduction

This chapter presents the results of an analysis of the economic, environmental, and fiscal impacts of energy subsidy reform in Saudi Arabia. As noted in various studies, a thorough and comprehensive assessment of the impacts of energy subsidy reform is vital for overcoming the barriers to reform and achieving successful implementation (Laan et al., 2010; Clements et al., 2013, 2014; Rentschler and Bazilian, 2017a, 2017b). The results of such impact analyses are needed by policymakers who must weigh the potential benefits of energy subsidy reform against the potential costs, while taking into account national capabilities and circumstances.

There is a myriad of impacts that can result from energy subsidy reform. Given the importance of assessing these impacts, the World Bank launched ESRAF, an initiative that guides countries towards implementing energy subsidy reforms successfully (Flochel and Gooptu, 2018). ESRAF lists and categorizes many of these impacts, including fiscal impacts, impacts on household consumption, impacts on firms and industrial competitiveness, economic and macroeconomic impacts, and impacts on externalities, including environmental externalities.

Different methods and models can be used to assess the different impacts of energy subsidy reform. These methodologies include 1) partial equilibrium models, 2) single-equation econometric models, 3) macro-econometric models, 4) computable general equilibrium (CGE) models, 5) dynamic stochastic general equilibrium (DSGE) models, 6) energy system models, and 7) integrated assessment models, along with hybrid approaches that combine one or more of the above methods (Ellis, 2010; Burns et al., 2018; Prina et al., 2020; Bassi et al., 2023).

To assess the impacts of energy subsidy reform, which is a price-based instrument, many of these methods and models have key data requirements, which include the price elasticities of energy demand (Burns et al., 2018). As noted in ESRAF's guidance, "ideally, the elasticities should be determined for each study through rigorous econometric regressions. However, this approach is more the exception than the rule, in part because the data needed to carry out credible regression

analysis is often not available” (Burns et al., 2018). The lack of price elasticities for Saudi Arabia, which was discussed in Chapter 2, contributes to the lack of comprehensive assessments for the impacts of energy subsidy reform in the country.

To address this gap and inform policymakers in Saudi Arabia, this chapter employs the estimated price elasticities from Chapter 2 to quantify the economic, environmental, and fiscal impacts of energy subsidy reform in Saudi Arabia. This chapter is structured as follows. Section 3.2 provides background on energy pricing policy in Saudi Arabia and showcases the country’s recent energy subsidy reform efforts. Section 3.3 draws from various theoretical discussions in the literature to provide a conceptual framework for the assessment of the economic, environmental, and fiscal impacts of energy subsidy reform. Section 3.4 reviews past studies that assessed some of these impacts, either at a global level or specifically for Saudi Arabia. Section 3.5 then introduces the methods that are used in this thesis to conduct the impact analysis. Section 3.6 presents and discusses the results of the impact analysis, while Section 3.7 concludes.

## **3.2 Background on Energy Subsidy Reform Efforts in Saudi Arabia**

The Saudi government has been regulating domestic energy prices for decades (WTO, 2005), but recent concerns over resource and fiscal sustainability have prompted two waves or episodes of energy subsidy reform. The first wave of energy subsidy reform was implemented on January 1, 2016, resulting in substantial increases in fuel, electricity, and water prices for industry and households. The second wave was subsequently implemented on January 1, 2018, focusing on a smaller subset of fuels. The 2018 reform was implemented alongside the introduction of a 5% value-added tax (VAT) on all goods and services. These initiatives were part of the Fiscal Balance Program (2016), suggesting that fiscal sustainability was the key driver of these reforms. Table 10 shows domestic energy prices in 2015, after the 2016 reform, and after the 2018 reform. Most of the domestic energy prices in 2015 had been nominally fixed at those levels for at least a decade, as the Saudi government did not revise domestic energy prices frequently. The percentage changes in Table 10 highlight the considerable increases that have been implemented over the 2015-2018 period. Nonetheless, although the reforms in

2016 and 2018 were extensive, there remains further scope for reform, as demonstrated by the last column in Table 10, which lists 2018 reference prices (i.e., what deregulated prices would be) for each energy product. Using 2022 reference prices would suggest even greater scope for further reform. For example, according to the EIA (2024a), the Brent oil spot price in 2022 was 100.93 USD per barrel, which is over 40% higher than the price in 2018.

While domestic energy prices in Saudi Arabia reached new levels in nominal terms following the reforms (e.g., in the case of gasoline, its price had never previously crossed the 1.0 Saudi Riyal (SR) per litre threshold prior to 2018), it is useful to see how prices compare in real terms, given that some prices were fixed in nominal terms for almost a decade or longer. Figure 7 illustrates the evolution of real energy prices between 2000 and 2018, demonstrating that, in most cases, reformed energy prices in 2018 were considerably higher than prices in 2000 in real terms. However, for some fuels, such as diesel for transport, the real price in 2018 was slightly lower than the real price in 2000, despite its doubling in nominal terms.

To mitigate the negative impacts of energy subsidy reform and the VAT on lower- and middle-income households, the Saudi government launched the Citizens' Account in 2018, a compensation scheme that compensates households for higher energy prices through monthly cash transfers (Arab News, 2017; Fiscal Balance Program, 2018).

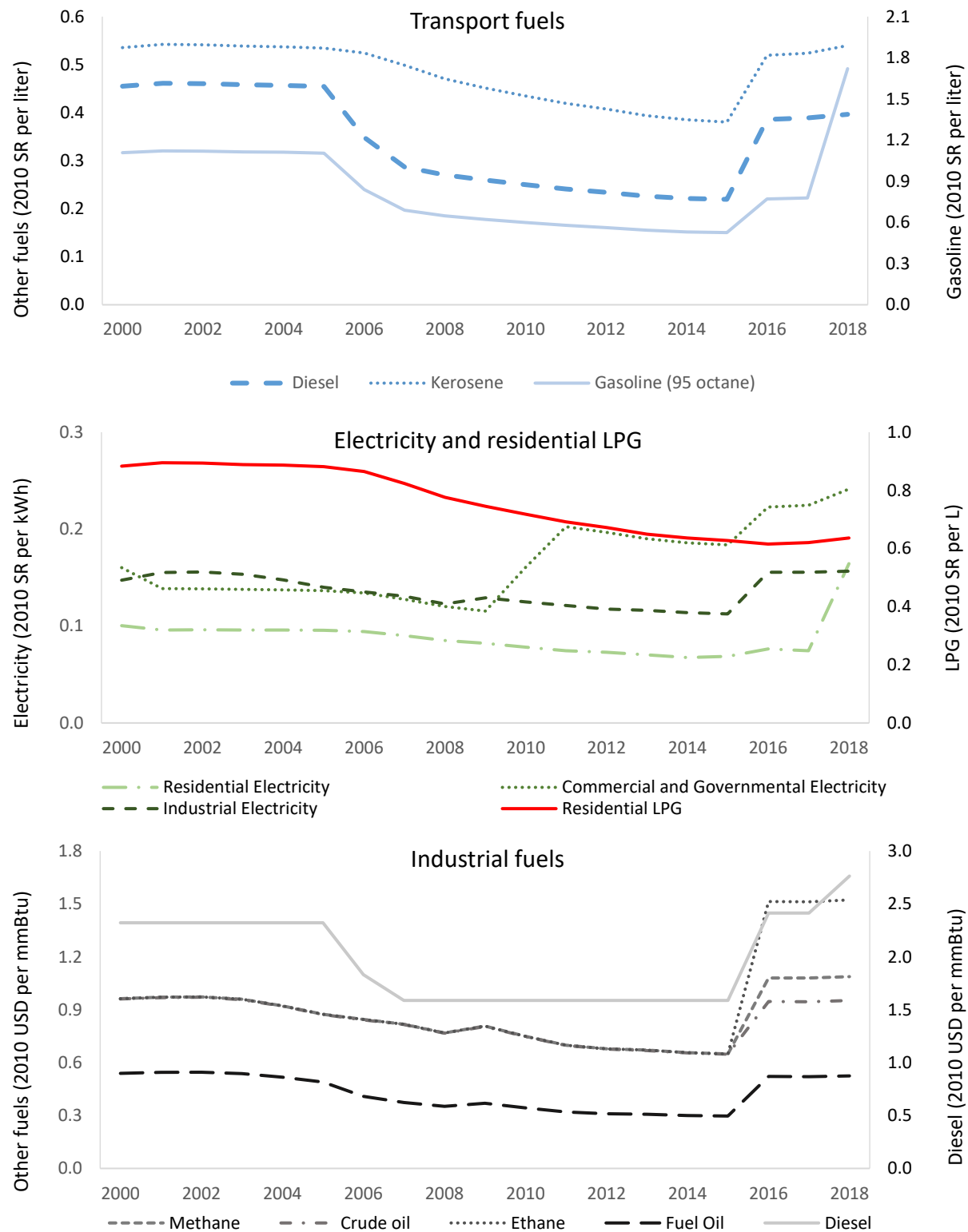
Since 2018, the Saudi government has implemented further minor reforms. With regard to gasoline prices, the Saudi government linked the domestic gasoline price to global prices in 2019, with adjustments occurring every quarter (Gasim and Aldubyan, 2020). In 2020, the government tightened this link as it started adjusting domestic gasoline prices every month. However, in July 2021, the Saudi government placed a cap on domestic gasoline prices as crude oil prices reached multi-year highs (Arab News, 2021). Since July 2021, gasoline prices have remained fixed at their cap, which was set at 2.18 SR per litre and 2.33 SR per litre for 91-octane and 95-octane gasoline, respectively (Saudi Aramco, 2025). Prices of most other energy products remained at their 2018 levels, albeit with a slight increase in the middle of 2020 following the VAT increase from 5% to 15% on almost all goods and services in response to COVID-19 (Al Arabiya, 2020). There have also been four gradual

increases in diesel prices (Namaa Zone, 2024; Arab News, 2025), from 0.52 SR to 0.63 SR per litre at the start of 2022, then up to 0.75 SR per litre at the start of 2023, and then up to 1.15 SR per litre at the start of 2024, and, most recently, rising to 1.66 SR per litre at the start of 2025. The last two diesel price increases were part of broader gradual reforms to industrial fuel and feedstock prices, which were implemented at the start of 2024 and 2025 (Riyad Capital, 2024; Arab News, 2025). Nevertheless, there remains significant scope for further energy subsidy reform, and the government seems to be following a gradual approach with minor annual increases in subsets of fuel prices (Aljazira Capital, 2025).

**Table 10** Nominal energy prices in Saudi Arabia between 2015 and 2018.

| <i>End-use sector:<br/>Energy product</i> | <b>Units</b>         | <b>Prices before 1st wave of<br/>reform (2015)</b> | <b>Prices after 1st wave of<br/>reform (2016-2017)</b> | <b>1<sup>st</sup> wave %<br/>change</b> | <b>Prices after 2nd wave of<br/>reform (2018)</b> | <b>2nd wave %<br/>change</b> | <b>Fully reformed prices for<br/>comparison (2018)</b> |
|-------------------------------------------|----------------------|----------------------------------------------------|--------------------------------------------------------|-----------------------------------------|---------------------------------------------------|------------------------------|--------------------------------------------------------|
| <b>Transport:</b>                         |                      |                                                    |                                                        |                                         |                                                   |                              |                                                        |
| 91 RON Gasoline                           | SR/L                 | 0.45                                               | 0.75                                                   | 67%                                     | 1.37                                              | 83%                          | 2.01                                                   |
| 95 RON Gasoline                           | SR/L                 | 0.60                                               | 0.90                                                   | 50%                                     | 2.04                                              | 127%                         | 2.01                                                   |
| Diesel                                    | SR/L                 | 0.25                                               | 0.45                                                   | 80%                                     | 0.47                                              | 5%                           | 2.19                                                   |
| Kerosene                                  | SR/L                 | 0.44                                               | 0.61                                                   | 39%                                     | 0.64                                              | 5%                           | 2.11                                                   |
| <b>Residential:</b>                       |                      |                                                    |                                                        |                                         |                                                   |                              |                                                        |
| Electricity: 0-2000 kWh                   | SR/kWh               | 0.05                                               | 0.05                                                   | 0%                                      | 0.19                                              | 278%                         | 0.31                                                   |
| Electricity: 2001-4000 kWh                | SR/kWh               | 0.10                                               | 0.10                                                   | 0%                                      | 0.19                                              | 89%                          | 0.31                                                   |
| Electricity: 4001-6000 kWh                | SR/kWh               | 0.12                                               | 0.20                                                   | 67%                                     | 0.19                                              | -6%                          | 0.31                                                   |
| Electricity: 6001+ kWh                    | SR/kWh               | 0.15 to 0.26                                       | 0.30                                                   | N/A                                     | 0.32                                              | 5%                           | 0.31                                                   |
| LPG                                       | SR/L                 | 0.72                                               | 0.72                                                   | 0%                                      | 0.75                                              | 5%                           | 0.91                                                   |
| <b>Commercial &amp; Governmental:</b>     |                      |                                                    |                                                        |                                         |                                                   |                              |                                                        |
| Electricity: commercial                   | SR/kWh               | 0.12 to 0.26                                       | 0.16 to 0.30                                           | N/A                                     | 0.21 to 0.32                                      | N/A                          | 0.31                                                   |
| Electricity: governmental                 | SR/kWh               | 0.26                                               | 0.32                                                   | N/A                                     | 0.34                                              | 5%                           | 0.31                                                   |
| <b>Industry &amp; Non-Energy Use:</b>     |                      |                                                    |                                                        |                                         |                                                   |                              |                                                        |
| Electricity                               | SR/kWh               | 0.14                                               | 0.18                                                   | 29%                                     | 0.19                                              | 5%                           | 0.31                                                   |
| Natural gas                               | USD/mmBtu            | 0.75                                               | 1.25                                                   | 67%                                     | 1.31                                              | 5%                           | 4.20                                                   |
| Ethane                                    | USD/mmBtu            | 0.75                                               | 1.75                                                   | 133%                                    | 1.84                                              | 5%                           | 4.73                                                   |
| Arab light crude oil                      | USD/bbl              | 4.24                                               | 6.35                                                   | 50%                                     | 6.67                                              | 5%                           | 74.12                                                  |
| Arab heavy crude oil                      | USD/bbl              | 2.67                                               | 4.40                                                   | 65%                                     | 4.62                                              | 5%                           | 71.97                                                  |
| Diesel                                    | USD/bbl              | 9.12                                               | 14.00                                                  | 54%                                     | 16.03                                             | 14%                          | 88.28                                                  |
| Heavy fuel oil                            | USD/bbl              | 2.08                                               | 3.80                                                   | 83%                                     | 3.99                                              | 5%                           | 61.45                                                  |
| Propane, butane, naphtha                  | % of reference price | 72% of naphtha's CIF price in Japan                | 80% of each fuel's export price to Japan               | N/A                                     | 80% of each fuel's export price to Japan + 5% VAT | N/A                          | 100% of each fuel's export price + 5% VAT              |

Notes: Years in parentheses. Sources for domestic energy prices are described in Chapter 2; sources for fully reformed prices are described in Chapter 3. The fully reformed price for both gasoline grades is set to the spot price for conventional gasoline in the US. Abbreviations: SR = Saudi Riyal; USD = United States Dollar; L = Liter; LPG = Liquefied Petroleum Gas; bbl = Barrel; mmBtu = Million British Thermal Units; toe = Tonne of Oil Equivalent; VAT = Value Added Tax; kWh = Kilowatt-Hour; RON = Research Octane Number; CIF = Cost + insurance + freight.



**Figure 7** Real energy prices in Saudi Arabia between 2000 and 2018.

Notes: Electricity prices averaged. Abbreviations: L = Liter; LPG = Liquefied Petroleum Gas; mmBtu = Million British Thermal Units; SR = Saudi Riyal; USD = United States Dollar.

### **3.3. Conceptual Framework**

#### **3.3.1 Measuring the economic impacts of energy subsidy reform**

Microeconomic theory provides tools for analyzing the economic impacts of a policy intervention like a tax or subsidy. Such impact analyses focus on the measurement of changes in economic (or social) welfare in an economy. These changes are generally measured by using metrics like consumer surplus, producer surplus, total surplus, and deadweight loss (Varian, 1992; Perloff, 2023). Deadweight loss, a measure of economic waste that is also referred to as a “welfare cost”, is often the primary metric used for quantifying the economic impact of a policy intervention (Harberger, 1964). Given Harberger’s pioneering work on deadweight loss, the areas that represent deadweight loss on supply and demand diagrams have come to be known as “Harberger Triangles” (Hines, 1999).

When an energy subsidy is introduced, it creates deadweight loss by allowing inefficient economic transactions to occur where consumers buy energy even though their willingness-to-pay for it is below its cost (Davis, 2017). When a subsidy is removed, whether partially or completely, it reduces or eliminates that economic waste (i.e., deadweight loss). The reduction or elimination of deadweight loss is equal to the economic gain (or welfare gain) due to energy subsidy reform.

Calculations of the deadweight loss eliminated by reducing energy subsidies generally depend on demand and supply curves. In most welfare analyses in the literature, the supply of energy is assumed to be perfectly elastic (Clements et al., 2013; Coady et al., 2015; Davis, 2017), as the energy sector has great potential to scale up supply in response to higher energy prices. In the analysis that follows in this thesis, the supply has also been assumed to be perfectly elastic, leaving behind only the demand curve as the key factor determining the magnitude of deadweight loss. Consumer surplus, an indicator that measures the area below a demand curve, is commonly used to calculate the welfare effect of a price change on consumers (Varian, 1992; Perloff, 2023). In addition to consumer surplus, there are other indicators that can be used to measure the welfare effects of price changes on consumers, including compensating variation, equivalent

variation, Laspeyres variation, and Paasche variation (Araar and Verme, 2019). Although the choice of indicator can influence the size of the welfare effect, it has been demonstrated that when the share of a good in total income is small, the welfare effects of price changes for that good as measured by these different indicators generally converge. Furthermore, Araar and Verme (2019) noted that “in the absence of any normative augment in favor of one particular measure, the sensible choice is CS [consumer surplus] for the simple reason that this measure is always the median measure”. In this thesis, consumer surplus is the indicator used to measure the welfare effects of energy subsidy reform in Saudi Arabia.

It is also important to discuss the reference price used in deadweight loss calculations. The reference price represents the equilibrium price of energy in an undistorted market, and it has major implications on deadweight loss calculations (Davis, 2017). Coady et al. (2015) provided a conceptual framework for calculating the welfare gains from energy subsidy reform, in which “supply costs” were used as the reference prices. They defined the supply cost as “the opportunity cost to a country of supplying the energy product to consumers (i.e., firms and households).” For internationally traded energy products like gasoline and diesel, Coady et al. (2015) used the international market price as the supply cost, while for non-traded energy products like electricity they used its marginal production cost instead. Davis (2017) adopted a similar conceptual framework, stating that “the correct measure of cost is the opportunity cost” and agreeing with Coady et al. (2015) that for traded energy products the international market price is the appropriate measure of opportunity cost.

The deadweight loss approach discussed above represents a partial equilibrium method for measuring the welfare changes that result from a policy intervention on a single commodity like gasoline, but a general equilibrium approach can also be used. A general equilibrium approach can capture further welfare changes that result from energy subsidy reform affecting the production and consumption of other commodities and markets across the economy. Studies have shown that the welfare changes measured using partial equilibrium models can offer reasonable approximations for the true economy-wide welfare change (Kokoski and Smith, 1987; Pizer et al., 2006).

In addition to deadweight loss, energy subsidy reform can reduce the negative externalities associated with energy consumption. As noted by Kolstad, (2011) “an externality exists when the consumption or production choices of one person or firm enters the utility or production function of another entity without that entity’s permission or compensation”. Externalities can be negative or positive, either representing a cost on other entities or a benefit to them. In the case of energy consumption, it is associated with multiple negative externalities (or external costs) like CO<sub>2</sub> emissions and air pollution (Parry et al., 2014). When a fuel is subsidized, it leads to excessive consumption, which not only causes deadweight loss but also leads to excessive CO<sub>2</sub> emissions and air pollution. Energy subsidy reform can thus deliver further welfare gains (beyond the deadweight loss reductions) by also reducing the external costs associated with energy consumption.

In this thesis, the estimated energy demand equations from Chapter 2 are combined with the appropriate reference prices for each energy product to calculate the deadweight loss reductions, external cost reductions, and total welfare changes due to energy subsidy reform.

### **3.3.2 Measuring the emission impacts of energy subsidy reform**

There are various methods and models that can be used to quantify the GHG emission impacts (also known as GHG effects) of a policy intervention, including bottom-up engineering models and top-down econometric models. Although it does not prescribe any specific method or model, the Greenhouse Gas Protocol (2024) has developed a standard that is widely used to estimate the GHG effects of policies and actions. This standard, known as the Policy and Action Standard, provides a general process that includes the following steps: 1) defining the policy to be assessed, 2) identifying the potential GHG effects that could result from the policy, 3) estimating the size of the GHG effects, 4) verifying the results, and 5) reporting them alongside the methodology used.

Estimating the size of the GHG effects, regardless of the method, generally requires the development of a baseline scenario and a policy scenario (Greenhouse Gas Protocol, 2024). Using energy subsidy reform as an example of a policy to be assessed, the baseline scenario would reflect GHG emissions, and the activity that is driving it, in the absence of energy subsidy reform, while the policy scenario would reflect GHG emissions,

and the activity that is driving it, if energy subsidy reform were to be undertaken. The difference between the baseline and policy scenario gives the GHG effect of the policy intervention. Many analyses focus on modelling an activity, such as energy consumption, that is causing GHG emissions instead of modelling emissions directly. The activity data is then multiplied by emission factors to obtain GHG emission estimates (Greenhouse Gas Protocol, 2024).

As was the case with the measurement of the economic impacts, the emission impacts from a policy intervention like energy subsidy reform can also be measured using a partial equilibrium or general equilibrium approach. Moreover, as discussed previously, it has been shown that the emission reductions that can be achieved from a climate policy intervention when measured using a partial equilibrium approach are a reasonable approximation for the true economy-wide emission reductions (Pizer et al., 2006).

This thesis measures the impacts of energy subsidy reform on GHG emissions in Saudi Arabia by combining the energy demand equations estimated using econometric methods in Chapter 2 with emission factors. My energy demand curves allow for calculating the level of energy consumption under baseline and policy scenarios for domestic energy prices, which are then subtracted and multiplied by the appropriate emission factors to obtain the GHG effects.

### **3.3.3 Measuring the fiscal costs and impacts of energy subsidy reform**

The fiscal impacts of energy subsidy reform can be estimated by measuring energy subsidies. As noted by Davis (2017), when the costs of energy subsidies are borne by the government, “the total subsidy is also the fiscal impact”. However, the costs of subsidies are not always borne by the government, as other actors in the economy can subsidize each other, such as domestic producers subsidizing consumers (Gooptu, 2019).

Nevertheless, even if domestic producers in a country are absorbing some of the costs, it likely ends up as a fiscal cost on the government through lower net profits for domestic producers and thus lower tax revenue for the government from those producers (Davis, 2017).

The type of cost that energy subsidies represent can differ between energy-importing and energy-exporting countries. In energy-importing countries, the magnitude of energy subsidies reflects a clear and direct fiscal cost, as the government makes expenditures that allow energy that is imported at international market prices to be sold at lower domestic prices. In energy-exporting countries like Saudi Arabia, the magnitude of energy subsidies may reflect only foregone revenues if energy is sold domestically at prices that are above domestic production costs but below international market prices. The term “explicit” has been used to describe energy subsidies that represent a direct fiscal cost on governments, while the term “implicit” has been used to describe energy subsidies that only represent foregone revenue (Krane, 2020). Since implicit energy subsidies represent an opportunity cost and not a direct cost, they have also been referred to as “opportunity cost subsidies” (Moerenhout and Irschlinger, 2020). Nevertheless, regardless of whether a country is a net importer of energy or a net exporter, and whether the energy subsidy represents a direct fiscal cost or an opportunity cost in terms of foregone revenue, it has been argued that international market prices are the appropriate measure of cost to use for measuring energy subsidies for traded energy products like gasoline and diesel (Davis, 2017).

The price-gap method is arguably the most widely used method to measure the fiscal cost of energy subsidies. The attractiveness of the price-gap method rests on its relative simplicity compared to other approaches. The price-gap method works by measuring the gap between the domestic price of an energy product and its reference price and multiplying that gap by the total quantity of energy consumed in a country (Koplow, 2009). The reference price is generally the international market price for traded energy products like gasoline and diesel, and the long-run marginal cost for non-traded energy products like electricity (Coady et al., 2015).

The price-gap method, however, does have some drawbacks. It overlooks economic effects like the consumer response to higher energy prices following energy subsidy reform. As consumers respond by reducing their demand for energy, it can offset some of the fiscal gain from raising domestic energy prices. To measure the fiscal impact of post-tax energy subsidy reform, Coady et al. (2015) did not use the price-gap estimate of

energy subsidies but instead introduced a formula that accounts for the reduction in the quantity of energy demanded due to increased energy prices. Coady et al. (2015) noted that the fiscal gain they measured was smaller than the price-gap estimate of energy subsidies given that their method “accounts for the price-induced reduction in energy use.”

The price-gap method also overlooks other important economic effects. As noted by Krane (2020), in the case of oil-exporting countries, the actual foregone revenue from energy subsidy reform could be lower than what is suggested by the price-gap estimate due to additional oil exports depressing the international oil price. In other words, the opportunity cost of providing energy subsidies in Saudi Arabia may be lower than the international market price. In fact, a recent study by Karanfil and Pierru (2021) discussed the issue of determining the appropriate opportunity cost for crude oil in Saudi Arabia and how market imperfections alter estimates. They argued that since Saudi Arabia is the world’s leading exporter of oil, the ‘small economy’ assumption that its exports will not influence international oil prices does not hold. They then estimated that the opportunity cost of a barrel of oil in Saudi Arabia could vary between 31% and 84% of the international oil price.

This thesis first measures the fiscal impacts of energy subsidy reform in Saudi Arabia using detailed energy price and consumption data and the price-gap method. It then attempts to refine the estimates of the fiscal impacts of energy subsidy reform by expanding on the price-gap method. This expansion captures the consumer response to energy subsidy reform in Saudi Arabia and how additional fuel exports may depress international fuel prices, both of which can offset the fiscal gain from energy subsidy reform.

## **3.4 Literature Review**

### **3.4.1 Welfare impacts of energy subsidy reform from the literature**

Both partial and general equilibrium approaches have been used to quantify the impacts of energy subsidy reform (Ahmadian et al., 2007; Ellis, 2010; Burniaux and Chateau, 2014; Balke et al., 2015; Coady et al., 2015, 2018; Aune et al., 2017; Davis, 2017; Black et al., 2023). The spatial scope of these studies varies from global to regional to country-specific. Moreover, the studies vary in their coverage of fuels when modelling the welfare impacts,

focusing on either a single fuel, a sub-set of fuels, or all major fossil fuels. Because of its relative simplicity, most studies in the literature use the partial equilibrium approach for measuring the welfare impacts of energy subsidy reform.

Using a partial equilibrium approach, studies have consistently shown that enormous global welfare gains could be achieved with energy subsidy reform. In the absence of country-specific price elasticity estimates for all countries and energy products, which are needed for an accurate partial equilibrium analysis, these studies have assumed an average elasticity value and applied it to all countries. For example, Coady et al. (2015, 2017, 2018) assumed that average gasoline and diesel price elasticities were -0.5 across all countries, while Davis (2017) assumed an average price elasticity of -0.6. Using these average elasticities, Coady et al. (2015), Davis (2017), and Coady et al. (2018) estimated massive global welfare gains from energy subsidy reform. Coady et al. (2015) and Coady et al. (2018) estimated the global welfare gain from eliminating post-tax energy subsidies to be 1.4 trillion USD globally in 2013, roughly 2% of global GDP in that year. Coady et al. (2018) broke down this global welfare gain by region, showing that the Middle East, North Africa, Afghanistan, and Pakistan region, which includes Saudi Arabia, accounts for almost 200 billion USD of this total global welfare gain. Focusing on gasoline and diesel subsidies only, Davis (2017) estimated the global deadweight loss that could be eliminated by gasoline and diesel subsidy reform to be 26 billion USD in 2014, while estimating the global welfare gain from reduced external costs to be 44 billion USD, taking their total welfare gain estimate up to 70 billion USD. Davis (2017) demonstrated that among all countries, Saudi Arabia had the potential to achieve the largest welfare gains from energy subsidy reform in 2014. In a more recent study, Black et al. (2023) estimated that full energy subsidy reform could produce global welfare gains of around 3.6% of global GDP in 2022.

Using a general equilibrium approach, a few studies have also found that massive welfare gains could be achieved globally with energy subsidy reform, although they discovered variations between oil-importing and oil-exporting countries. Burniaux and Chateau (2014) estimated that the phase out of fossil fuel subsidies could raise welfare by 0.2% globally in their central scenario. They demonstrated that for oil-exporting countries, the welfare gains

are relatively larger following unilateral energy subsidy reform, but relatively smaller following multilateral reforms across all countries because of the impact of lower global fossil fuel demand on international fossil fuel prices. They also found the opposite to be true in oil-importing countries. Nevertheless, even in a scenario of multilateral reform that depresses international fossil fuel prices, Burniaux and Chateau (2014) still estimated a net welfare gain in oil-exporting countries. Balke et al. (2015) and Aune et al. (2017) also observed similar welfare results using general equilibrium models. Both studies found that in oil-exporting countries energy subsidy reform is welfare enhancing, with Aune et al. (2017) estimating a net welfare gain of up to 9% of GDP in OPEC countries.

Looking at studies that focused exclusively on Saudi Arabia, there appear to be only two that have measured the welfare gains of energy subsidy reform, both of which used a partial equilibrium approach and Saudi-specific price elasticities. Atalla et al. (2018) used their estimated gasoline price elasticity to measure the welfare changes from the 2016 wave of gasoline price reform in Saudi Arabia. They measured the welfare gain to be up to 1.7 billion 2010 USD. Aldubyan and Gasim (2021) quantified the welfare changes that resulted from the 2018 wave of energy subsidy reform (excluding the impact of the 2016 wave) to be 2.3 billion USD for gasoline and 1.0 billion USD for residential electricity.

However, there appear to be no studies that estimated the welfare impacts of energy subsidy reform in Saudi Arabia for energy products other than gasoline and residential electricity, and no studies that examined the combined economy-wide welfare impacts across all energy products and end-use sectors using Saudi-specific elasticities. One possible reason behind this gap in the literature is the lack of price elasticity estimates for all energy products in Saudi Arabia. These price elasticities are a necessary input for conducting a welfare analysis that avoids strong assumptions about these fundamental parameters, which can affect the welfare impact analysis significantly.

In this thesis, I use my estimated price elasticities from Chapter 2 to accurately and comprehensively measure energy subsidy reform's welfare impacts in Saudi Arabia across all energy products and end-use sectors using a partial equilibrium framework.

### **3.4.2 Emission impacts of energy subsidy reform from the literature**

Different methodologies have been used to quantify the emission impacts (or GHG effects) of energy subsidy reform, including 1) partial equilibrium models, 2) macro-econometric models, 3) CGE models, 4) DSGE models, and 5) systems dynamics models (Ellis, 2010; Burns et al., 2018; Bassi et al., 2023). In their review of six studies that used different approaches, Ellis (2010) observed that all six studies had estimated significant CO<sub>2</sub> emission reductions from energy subsidy reform, ranging from 1.1% in 2010 to 18% in 2050, with variations in the estimates due to variations in the country and fuel coverage across the studies. In a review by Bassi et al. (2023), they found that studies typically estimated global fossil fuel subsidy reform to reduce emissions by around 1% to 10% by 2030, with the estimate varying significantly depending on the base year chosen, the definition of subsidies used (as discussed in Chapter 1), the country and fuel coverage, and the selected methodology.

Using a partial equilibrium approach, studies have shown that meaningful reductions in global GHG emissions could be achieved with energy subsidy reform, but there appears to be significant variation in the estimates despite using a similar methodology. As discussed previously, in the absence of country-specific price elasticity estimates, which are needed for an accurate impact analysis, many of these studies assumed an elasticity value in their calculations. Using such assumptions, Coady et al. (2015, 2018) estimated that global CO<sub>2</sub> emissions would have fallen by over 20% in 2013 in response to the removal of post-tax energy subsidies, with the biggest reduction being achieved in the Middle East and North Africa region. In contrast, Kuehl et al. (2021) found that fossil fuel subsidy reform in 32 countries would generate annual emission reductions of only 2% by 2021, rising to a maximum of 6% by 2025, with the reduction remaining largely fixed at around 6% from 2025 onwards. Black et al. (2023) estimated that the full removal of post-tax energy subsidies could reduce global fossil fuel CO<sub>2</sub> emissions by 43% below baseline by 2030, which they estimated to be equivalent to a 34% reduction below the 2019 emissions level.

Looking at the few studies that focused exclusively on Saudi Arabia, the consensus appears to be that there is strong emission reduction potential in the country, although there is a lack of price elasticities for accurate measurement. Using average price

elasticities and a partial equilibrium model, Black et al. (2023) showed that the removal of pre-tax energy subsidies in Saudi Arabia could reduce fossil fuel CO<sub>2</sub> emissions by around 50% below baseline by 2030, while the removal of post-tax subsidies would raise this reduction to around 70%. Also using a partial equilibrium model, Kuehl (2021) estimated that fossil fuel subsidy reform could reduce emissions in Saudi Arabia by 19.3% by 2030, which was the second largest reduction they estimated among 32 countries, behind only China. Using Saudi-specific elasticities and a partial equilibrium model, Aldubyan and Gasim (2021) found that the CO<sub>2</sub> emission reductions that were achieved in 2018 due to partial energy subsidy reform amounted to 4.6 Mt for gasoline and 5.6 Mt for residential electricity. Using a CGE model, Durand-Lasserve et al. (2020) estimated that full energy subsidy reform would lead to a 35% reduction in energy-related CO<sub>2</sub> emissions in Saudi Arabia by 2030 when compared to a baseline. However, Durand-Lasserve et al. (2020) could only use Saudi-specific price elasticities for gasoline and electricity in their CGE model. Given the absence of other price elasticities for the country, as discussed in Chapter 2, Durand-Lasserve et al. (2020) were forced to make assumptions regarding the consumer price response for the other major energy products that are consumed in Saudi Arabia.

In this thesis, I use my estimated price elasticities from Chapter 2 to accurately and comprehensively measure energy subsidy reform's CO<sub>2</sub> emission impacts in Saudi Arabia across all energy products and end-use sectors using a set of partial equilibrium energy demand models.

### **3.4.3 Fiscal costs and impacts of energy subsidy reform from the literature**

Since the fiscal cost of global energy subsidies was already discussed in Chapter 1, this section will focus on the fiscal costs for Saudi Arabia only. Saudi Arabia's domestic fuel prices have generally been set below international market prices but above domestic production costs, so energy subsidies in Saudi Arabia are generally described as "implicit", resulting in foregone revenue for the government (Krane, 2013; Charles et al., 2014; Krane et al., 2020). Therefore, estimates of the magnitude of energy subsidies in Saudi Arabia generally reflect the fiscal gain that can be achieved through energy subsidy reform.

There are several economy-wide estimates that reveal the existence of large energy subsidies in Saudi Arabia, all of which relied on the price-gap method. Taylor (2020) estimated fossil fuel subsidies in Saudi Arabia at roughly 45 billion 2018 USD in 2017. The IMF (2024) estimated explicit (or pre-tax) Saudi energy subsidies at 129.3 billion 2021 USD in 2022 (Black et al., 2023), while the IEA (2024) estimated them at 76.9 billion USD in the same year. In all these studies, Saudi Arabia ranks among the top energy-subsidizing countries, with Saudi energy subsidies accounting for up to 10% of the global total.

A few studies have focused on calculating energy subsidies for specific fuels in Saudi Arabia. For petroleum products, Alyousef and Stevens (2011) compared domestic energy prices in Saudi Arabia to production costs in the 2000s. The costs were derived using a simplified oil refining model. For natural gas, they used an estimate of the average cost that accounts for both the production of associated and non-associated gas. Using their model, they found that Saudi Arabia did not *explicitly* subsidize those fuels. In other words, there was no expenditure by the government to subsidize the sale of domestic petroleum products. For electricity, Alyousef and Stevens (2011) used an average marginal cost estimate of 9.92 cents per kilowatt-hour (kWh) as the reference price and estimated 13.3 billion USD in electricity subsidies in 2010. They did not provide subsidy estimates for crude oil used directly or natural gas liquids (NGLs). Charles et al. (2014) estimated gasoline and diesel subsidies, the latter for the transport sector only, to be 14 billion and 13 billion USD, respectively, in 2011. Davis (2017) measured gasoline and diesel subsidies in Saudi Arabia to be almost 20 billion USD in 2014. These studies also relied on the price-gap method.

A few studies have acknowledged that the price gap method does not accurately capture the fiscal gain from energy subsidy reform due to the consumer response to higher energy prices, providing estimates of the fiscal gain that account for this response. Coady et al. (2015, 2018) estimated this fiscal gain from the removal of post-tax energy subsidies to be 3.0 trillion USD globally in 2013, compared to a price-gap estimate of 4.9 trillion USD for global energy subsidies in that year. The considerable difference between both estimates stems from the reduction in demand that results from their use of a price elasticity of -0.5

for all countries across all petroleum products and electricity. Similarly, Black et al. (2023) estimated a potential fiscal gain of 4.4 trillion USD in 2022 globally from the removal of post-tax energy subsidies after accounting for the price-induced response of consumers, an estimate that is also considerably lower than their price-gap estimate of 7.0 trillion USD for post-tax energy subsidies.

In this thesis, I use my estimated price elasticities from Chapter 2 to comprehensively measure energy subsidy reform's fiscal costs and impacts in Saudi Arabia across all fuels and end-use sectors. I then develop and apply a novel method that accounts for both the domestic consumer response to subsidy removal and the international market's response to additional fuel exports when measuring the fiscal impacts. Other than Krane et al. (2020), who acknowledged the latter's effect and how it may cause the foregone revenue from subsidy removal to be smaller than the price-gap estimate, no study has measured the fiscal impacts of energy subsidy reform while accounting for both market effects.

## 3.5 Methods

### 3.5.1 Measuring the welfare changes due to energy subsidy reform

Following the conceptual framework used by Coady et al. (2015), Davis (2017), Atalla et al. (2018), and Coady et al. (2018), I combine my estimated energy demand equations (and specifically, my estimated price elasticities of energy demand) with the appropriate reference prices for each energy product in each end-use sector to calculate the deadweight loss eliminated due to energy subsidy reform. In line with the literature, I assume that supply is perfectly elastic, making my analysis dependent on the energy demand equations and reference price assumptions. However, unlike the previously listed studies, I expand the equations to allow for an analysis of both partial and complete instances of energy subsidy reform. (Previous studies only presented simplified versions of these equations that can only be used to measure the impacts of full energy subsidy reform.)

Taking Equation [7] from Chapter 2, which is a constant elasticity demand equation, and taking the exponential of both sides to cancel the logs yields:

$$E_t^{j,k} = A_t^{j,k} P_t^{j,k \zeta^{j,k}} \quad [8]$$

where  $E_t^{j,k}$  and  $P_t^{j,k}$  are respectively the quantity of energy product  $j$  demanded in end-use sector  $k$  in year  $t$  and its price, while the parameter  $A_t^{j,k}$  captures the combined effect of all the other variables from Equation [7] in Chapter 2. The coefficient  $\zeta^{j,k}$  is the estimated elasticity, which could be a short- or long-run price elasticity.

I solve for  $A_t^{j,k}$  using energy demand data, price data, and my estimated price elasticities of energy demand. The value of this parameter will vary depending on whether a short- or long-run price elasticity is used for calibration. The calibrations are done for each energy demand equation, covering all energy products and end-use sectors. Once the parameters are calibrated, the changes in deadweight loss can be estimated for both the short and long run.

I calculate the change in deadweight loss ( $\Delta DWL_t^{j,k}$ ) that occurs when the price of an energy product  $j$  in sector  $k$  is reformed as follows:

$$\Delta DWL_t^{j,k} = (P_{t,ref}^{j,k} - P_{t,b}^{j,k}) * E_{t,b}^{j,k} - (P_{t,ref}^{j,k} - P_{t,a}^{j,k}) * E_{t,a}^{j,k} - \int_{P_{t,b}^{j,k}}^{P_{t,a}^{j,k}} E_t^{j,k} dP_t^{j,k} \quad [9]$$

where  $P_{t,b}^{j,k}$  is the energy price before reform,  $P_{t,a}^{j,k}$  the energy price after reform, and  $P_{t,ref}^{j,k}$  the reference price, which should represent the market equilibrium price of energy in an undistorted market.  $E_{t,b}^{j,k}$ ,  $E_{t,a}^{j,k}$ ,  $E_{t,ref}^{j,k}$  are the corresponding demand quantities at those prices. With full reform ( $P_{t,ref}^{j,k} = P_{t,a}^{j,k}$ ), the second term on the right-hand side (RHS) falls to zero, leaving behind the more familiar equation used by Coady et al. (2015), Davis (2017), and Coady et al. (2018).

Substituting Equation [8] into Equation [9] yields:

$$\Delta DWL_t^{j,k} = (P_{t,ref}^{j,k} - P_{t,b}^{j,k}) * E_{t,b}^{j,k} - (P_{t,ref}^{j,k} - P_{t,a}^{j,k}) * E_{t,a}^{j,k} - \int_{P_{t,b}^{j,k}}^{P_{t,a}^{j,k}} A_t^{j,k} P_t^{j,k \zeta^{j,k}} dP_t^{j,k} \quad [10]$$

Evaluating the integral leads to the final equation:

$$\Delta DWL_t^{j,k} = (P_{t,ref}^{j,k} - P_{t,b}^{j,k}) * E_{t,b}^{j,k} - (P_{t,ref}^{j,k} - P_{t,a}^{j,k}) * E_{t,a}^{j,k}$$

$$-\frac{A_t^{j,k}}{(1+\zeta^{j,k})} \left( P_{t,a}^{j,k(1+\zeta^{j,k})} - P_{t,b}^{j,k(1+\zeta^{j,k})} \right) \quad [11]$$

The welfare gained from reducing deadweight loss is simply the negative of the change in deadweight loss.

I then calculate the change in total external costs ( $\Delta TEC_t^{j,k}$ ) due to energy subsidy reform by looking at the difference in energy consumption before and after energy subsidy reform, which is then multiplied by Saudi-specific per-unit external cost estimates from the literature ( $PUEC_t^{j,k}$ ):

$$\Delta TEC_t^{j,k} = (E_{t,a}^{j,k} - E_{t,b}^{j,k}) * PUEC_t^{j,k} \quad [12]$$

These country-specific per-unit external costs were estimated by a team at the IMF on a country-by-country basis (Parry et al., 2014), and they vary by energy product and sector and encompass multiple components. The combustion of fossil fuels produces CO<sub>2</sub> emissions and air pollution, two critical components of these external costs. Parry et al. (2014) calculated the per-unit external cost of CO<sub>2</sub> by combining data on the social cost of carbon with data on the carbon content of fuels for all countries. As for air pollution, they calculated the externality by assessing how much air pollution people in different countries are exposed to due to fossil fuel combustion, the relationship between air pollution exposure and health, along with assumptions to monetize those negative health effects in each country.

Some fuels also produce other negative externalities beyond CO<sub>2</sub> emissions and air pollution. For example, the use of gasoline and diesel in vehicles leads to congestion and accidents. Parry et al. (2014) estimated the external costs of congestion using a city-level database to estimate travel delays, which were then monetized based on country-level wage data. As for road accidents, the externalities were calculated based on country-level mortality data along with assumptions for the costs of medical expenses, property damage, and non-fatal injuries in each country.

It should also be noted that some fuels, specifically those used as feedstock, produce smaller emission externalities. For example, the petrochemical subsector's use of fuels like

natural gas as a feedstock generates limited CO<sub>2</sub> emissions since combustion does not take place, with most of the carbon being stored in the chemical product that is produced from the feedstock.<sup>8</sup>

Finally, I calculate the change in welfare ( $\Delta W_t^j$ ) due to energy subsidy reform by summing the reductions in DWL and total external costs:

$$\Delta W_t^{j,k} = -\Delta DWL_t^{j,k} - \Delta TEC_t^{j,k} \quad [13]$$

### 3.5.2 Measuring the emission reductions due to energy subsidy reform

This thesis measures the impacts of energy subsidy reform on GHG emissions in Saudi Arabia by combining the energy demand equations from Chapter 2 with emission factors, holding all other variables (like income) fixed. In line with this conceptual framework, the reduction in CO<sub>2</sub> emissions due to energy subsidy reform is calculated by multiplying the difference in energy consumption before and after energy subsidy reform by the appropriate emission factor from the literature ( $EF^{j,k}$ ):

$$\Delta CO_{2t}^{j,k} = (E_{t,a}^{j,k} - E_{t,b}^{j,k}) * EF^{j,k} \quad [14]$$

### 3.5.3 Measuring the fiscal impacts due to energy subsidy reform

#### 3.5.3.1 The fiscal impacts of full energy subsidy reform

This thesis measures the fiscal impacts of energy subsidy reform using equations that build complexity, starting from the price-gap equation. This equation provides the simplest approach for measuring energy subsidies and is expressed as follows:

$$S_t^{j,k} = FI_t^{j,k} = (P_{t,ref}^{j,k} - P_{t,b}^{j,k})E_{t,b}^{j,k} \quad [15]$$

where  $S_t^{j,k}$  denotes the price-gap estimate of the subsidy for energy product  $j$  in sector  $k$  in year  $t$ . For energy-importing countries, the price-gap estimate generally represents savings

---

<sup>8</sup> Although feedstock use for plastic production generates smaller global warming and air pollution externalities due to the absence of combustion, there can be other negative impacts through plastic pollution. For example, one study recently estimated the economic costs of each tonne of marine plastic, which can cause extensive damage to marine ecosystems, to be between 3300 and 33000 USD (Beaumont et al., 2019). However, the external costs of plastic pollution are beyond the scope of this thesis.

for the government (i.e., by how much fiscal expenditure could be reduced with energy subsidy reform), while in energy-exporting countries the price-gap estimate generally represents foregone revenue (i.e., by how much fiscal revenue could be increased with energy subsidy reform). Therefore, the price-gap estimate also represents the fiscal impact of energy subsidy reform, denoted by  $FI_t^{j,k}$ .

It is important to note that Equation [15] can only be used to estimate the fiscal impact of full energy subsidy reform, where the term “full” denotes raising the domestic energy price up to the reference price, such that  $P_{t,a}^{j,k} = P_{t,ref}^{j,k}$ . Equation [15] cannot be used to assess the fiscal impacts of partial instances of energy subsidy reform, where the domestic price is raised to a higher level but remains below the reference price ( $P_{t,b}^{j,k} < P_{t,a}^{j,k} < P_{t,ref}^{j,k}$ ).

For energy-exporting countries like Saudi Arabia and for energy products that can be exported, Equation [15] can be re-expressed to separate the impact of additional fuel exports on fiscal revenue by adding and subtracting the term  $P_{t,ref} E_{t,ref}^{j,k}$  as follows:

$$S_t^{j,k} = FI_t^{j,k} = P_{t,ref}^{j,k} \left( E_{t,ref}^{j,k} + (E_{t,b}^{j,k} - E_{t,ref}^{j,k}) \right) - P_{t,b}^{j,k} E_{t,b}^{j,k} \quad [16]$$

The right-hand side of Equation [16] captures the revenue from selling the domestic quantity consumed ( $E_{t,ref}^{j,k}$ ) at the fully reformed domestic price ( $P_{t,ref}^{j,k}$ ) plus the revenue from exporting the domestically saved fuel ( $E_{t,b}^{j,k} - E_{t,ref}^{j,k}$ ) at the export price ( $P_{t,ref}^{j,k}$ ) minus the previous level of revenue prior to energy subsidy reform ( $P_{t,b}^{j,k} E_{t,b}^{j,k}$ ). The use of Equation [16] requires energy price elasticities as an input to obtain the level of domestic fuel consumption ( $E_{t,ref}^{j,k}$ ), which can be estimated by inserting the appropriate reference price into Equation [8].

In countries like Saudi Arabia, it is possible that policymakers decide to keep some or all the saved fuel rather than export it in order to achieve a certain policy objective, so a parameter ( $\mu_t^{j,k}$ ) can be introduced into Equation [16] that reflects how much of the quantity of fuel saved domestically is exported. This parameter can be set to vary between 0 and 1.

$$S_t^{j,k} = FI_t^{j,k} = P_{t,ref}^{j,k} \left( E_{t,ref}^{j,k} + \mu_t^{j,k} (E_{t,b}^{j,k} - E_{t,ref}^{j,k}) \right) - P_{t,b}^{j,k} E_{t,b}^{j,k} \quad [17]$$

At  $\mu_t^{j,k} = 1$ , where all the domestically saved fuel is exported, it can be shown that Equation [17] collapses back into the original price-gap equation, which is Equation [15].

### 3.5.3.2 The fiscal impacts of partial energy subsidy reform

Equation [15] can only be used to estimate the fiscal impact of full energy subsidy reform, where the domestic energy price is raised all the way up to the reference price. Equation [15] cannot be used to assess the fiscal impact of partial energy subsidy reform, where the domestic price is raised but remains below the reference price. Surprisingly, there appear to be no studies in the literature that presented the equations needed to assess the fiscal impacts of partial energy subsidy reform. These fiscal impacts can be calculated by utilizing the price-gap equation. Specifically, the fiscal impact of partial energy subsidy reform can be expressed as the difference between the price gap equations for the magnitude of energy subsidies before and after partial energy subsidy reform:

$$\Delta S_t^{j,k} = FI_t^{j,k} = (P_{t,ref}^{j,k} - P_{t,b}^{j,k}) E_{t,b}^{j,k} - (P_{t,ref}^{j,k} - P_{t,a}^{j,k}) E_{t,a}^{j,k} \quad [18]$$

where  $\Delta S_t^{j,k}$  denotes the change in the magnitude of the price-gap estimate of the subsidy for energy product  $j$  in sector  $k$  in year  $t$ . This change in the magnitude of the subsidy provides an estimate of the fiscal impact, denoted by  $FI_t^{j,k}$ , which can represent either fiscal savings or a fiscal revenue uplift. It can be demonstrated using Equation [18] that in the event of full energy subsidy reform, such that  $P_{t,a}^{j,k} = P_{t,ref}^{j,k}$  and  $E_{t,a}^{j,k} = E_{t,ref}^{j,k}$ , Equation [18] collapses to give the familiar price-gap equation.

Equation [18] can be re-expressed to highlight the fiscal gain from selling domestically saved fuel at the higher international fuel price:

$$\Delta S_t^{j,k} = FI_t^{j,k} = P_{t,a}^{j,k} E_{t,a}^{j,k} - P_{t,b}^{j,k} E_{t,b}^{j,k} + (E_{t,b}^{j,k} - E_{t,a}^{j,k}) P_{t,ref}^{j,k} \quad [19]$$

The right-hand side of Equation [19] captures the revenue from selling the new domestic quantity consumed ( $E_{t,a}^{j,k}$ ) at the post-partial-reform price ( $P_{t,a}^{j,k}$ ), the previous revenue

from selling the pre-partial-reform quantity consumed ( $E_{t,b}^{j,k}$ ) at the pre-partial-reform price ( $P_{t,b}^{j,k}$ ), and the revenue from exporting and selling the domestically saved fuel ( $E_{t,b}^{j,k} - E_{t,a}^{j,k}$ ) at the international fuel price  $P_{t,ref}^{j,k}$ .

As noted previously, in countries like Saudi Arabia it is possible that policymakers decide to keep some or all of the saved fuel rather than export it in order to achieve a certain policy objective, so the parameter ( $\mu_t^{j,k}$ ) can be introduced into Equation [19] to reflect how much domestically saved fuel is exported.<sup>9</sup> This parameter can be set to vary between 0 and 1.

$$\Delta S_t^{j,k} = FI_t^{j,k} = P_{t,a}^{j,k} E_{t,a}^{j,k} - P_{t,b}^{j,k} E_{t,b}^{j,k} + \mu_t^{j,k} (E_{t,b}^{j,k} - E_{t,a}^{j,k}) P_{t,ref}^{j,k} \quad [20]$$

At  $\mu_t^{j,k} = 1$ , where all the domestically saved fuel is exported, it can be shown that Equation [20] collapses back into Equation [18].

### **3.5.3.3 What if full energy subsidy reform depresses the international fuel price?**

As noted in the conceptual discussion, additional fuel exports from a country like Saudi Arabia may be enough to depress the international fuel price, potentially leading to a relatively lower fiscal gain from energy subsidy reform.

Focusing only on the impact of full energy subsidy reform, I incorporate this effect by first adding a term to Equation [17] that distinguishes between the new international fuel price under the new market equilibrium, where international markets respond to additional Saudi fuel exports, and the initial international fuel price that prevailed in the market prior to energy subsidy reform implementation.

$$S_t^{j,k} = FI_t^{j,k} = P_{t,ref}^{j,k} (E_{t,ref}^{j,k} + \mu_t^{j,k} (E_{t,b}^{j,k} - E_{t,ref}^{j,k})) - P_{t,b}^{j,k} E_{t,b}^{j,k} +$$

---

<sup>9</sup> When fuel is saved domestically in an oil-exporting country like Saudi Arabia, decisionmakers have the option to either 1) export the saved fuel or 2) produce less fuel. Many oil-exporting countries are members of OPEC, but since OPEC places quotas on production and not exports (Gault et al., 1999), a binding OPEC production quota would not affect a country's ability to export domestically saved fuel. Since additional fuel exports are expected to generally generate higher revenues for the government, it is more likely than not that decisionmakers will export all the saved fuel (i.e.,  $\mu_t = 1$ ).

$$(P_{t,ref}^{j,k} - P_{t,initialref}^{j,k})X_{t,initialref}^{j,k} \quad [21]$$

where  $P_{t,initialref}^{j,k}$  denotes the initial international fuel price that prevailed prior to energy subsidy reform, while  $X_{t,initialref}^{j,k}$  denotes the initial level of fuel exports prior to energy subsidy reform. If the international market does not respond to additional fuel exports, such that  $P_{t,ref}^{j,k} = P_{t,initialref}^{j,k}$ , or if the initial level of fuel exports is zero, then Equation [21] collapses back into Equation [17].

Equation [21] can be used to estimate the fiscal impact of full energy subsidy reform in Saudi Arabia while allowing 1) domestic consumers to respond to higher domestic energy prices and 2) the international market to respond to additional Saudi fuel exports via lower international fuel prices. Therefore, there are two variables to solve for in Equation [21]: the level of domestic fuel demand following full energy subsidy reform ( $E_{t,ref}^{j,k}$ ) and the international fuel price after it adjusts to a new market equilibrium ( $P_{t,ref}^{j,k}$ ). These two variables can be obtained by solving the following system of equations:

$$\frac{E_{t,ref}^{j,k} - E_{t,b}^{j,k}}{E_{t,b}^{j,k}} = \zeta_{j,k} \frac{P_{t,ref}^{j,k} - P_{t,b}^{j,k}}{P_{t,b}^{j,k}} \quad [22]$$

$$\frac{P_{t,ref}^{j,k} - P_{t,initialref}^{j,k}}{P_{t,initialref}^{j,k}} = \frac{1}{\eta_{j,k}} \frac{\mu_{t,j,k}(E_{t,b}^{j,k} - E_{t,ref}^{j,k})}{X_{t,initialref}^{j,k}} \quad [23]$$

These equations can be solved for each exported fuel  $j$  in sector  $k$  in year  $t$  to obtain the new domestic level of fuel consumption ( $E_{t,ref}^{j,k}$ ) and the new international fuel price ( $P_{t,ref}^{j,k}$ ) after full energy subsidy reform.

Equations [22] and [23] represent two (rearranged) elasticity equations: The first elasticity equation (for  $\zeta$ ) relates the percentage change in domestic fuel consumption in Saudi Arabia to the percentage change in the domestic fuel price that occurs following removal of the fuel subsidy. The second elasticity equation (for  $\eta$ ) relates the percentage change in Saudi fuel exports to the percentage change in the international fuel price following removal of the fuel subsidy in Saudi Arabia. The second elasticity's inverse ( $1/\eta$ ) reflects how the international fuel price responds to additional Saudi fuel exports. Both elasticities are Saudi-specific elasticities that can be estimated. The domestic fuel price elasticities ( $\zeta$ ) were estimated in Chapter 2 while the elasticity of the international fuel price with respect to Saudi fuel exports ( $1/\eta$ ) was obtained from the literature.

Equation [22] and Equation [23] are standard formulations of arc elasticities. There are different types of elasticities like arc and point elasticities.<sup>10</sup> Both equations could have been written as point elasticity formulations instead but doing so introduced challenges for finding a symbolic solution to the system. For small price changes, arc elasticities and point elasticities are almost identical but diverge for larger price changes (Allen and Lerner, 1934). Nevertheless, in Appendix B, I show how arc elasticity values can be derived from point elasticity estimates for a range of price increases. For the domestic market response, which can involve large percentage increases in domestic energy prices, I derive arc elasticities

---

<sup>10</sup> Even for the arc elasticity, there are several formulations that can be used, as noted by Morrill (1983), and the choice of formulation often depends on "priorities or preferences". For Equation [22] and [23], a choice was made on the form of the arc elasticity with the aim of simplifying the procedure of symbolically solving the system of equations.

from my point elasticity estimates (see Appendix B). For the international market response, which involves only small percentage changes in Saudi fuel exports, the arc and point elasticities converge.

Solving the system of Equation [22] and Equation [23] gives symbolic solutions for  $E_{t,ref}^{j,k}$  and  $P_{t,ref}^{j,k}$ , which are shown by Equation [24] and Equation [25]. Given the length of the symbolic solutions, the parameters  $\tau$ ,  $\phi$ , and  $\omega$  have been defined to simplify them. These parameters are given in Equation [26], Equation [27], and Equation [28].

$$E_{t,ref}^{j,k} = E_{t,b}^{j,k} \frac{\tau_t^{j,k}}{\phi_t^{j,k}} \quad [24]$$

$$P_{t,ref}^{j,k} = P_{t,initialref}^{j,k} \frac{\omega_t^{j,k}}{\phi_t^{j,k}} \quad [25]$$

Where,

$$\tau_t^{j,k} = 1 + \frac{\zeta^{j,k}}{P_{t,b}^{j,k}} \left( P_{t,initialref}^{j,k} + \frac{\mu_t^{j,k} E_{t,b}^{j,k} P_{t,initialref}^{j,k}}{X_{t,initialref}^{j,k} \eta^{j,k}} - P_{t,b}^{j,k} \right) \quad [26]$$

$$\phi_t^{j,k} = 1 + \left( \frac{\mu_t^{j,k} \zeta^{j,k} E_{t,b}^{j,k} P_{t,initialref}^{j,k}}{X_{t,initialref}^{j,k} \eta^{j,k} P_{t,b}^{j,k}} \right) \quad [27]$$

$$\omega_t^{j,k} = 1 + \left( \frac{\mu_t^{j,k} \zeta^{j,k} E_{t,b}^{j,k}}{X_{t,initialref}^{j,k} \eta^{j,k}} \right) \quad [28]$$

Several interesting features can be observed in Equations [24] through [28]. When the domestic price elasticity of energy demand is zero (i.e.,  $\zeta^{j,k} = 0$ ), domestic consumers do not respond to higher energy prices, and the parameters  $\tau_t^{j,k}$  and  $\phi_t^{j,k}$  become equal to one, such that the level of domestic energy consumption following full energy subsidy reform remains unchanged (i.e.,  $E_{t,ref}^{j,k} = E_{t,b}^{j,k}$ ). Similarly, when domestic consumers do not respond to higher domestic energy prices, the parameters  $\omega_t^{j,k}$  and  $\phi_t^{j,k}$  also become equal to one, such that the international fuel price after full subsidy reform remains unchanged (i.e.,  $P_{t,ref}^{j,k} = P_{t,initialref}^{j,k}$ ) since there are no additional fuel exports.

Plugging Equation [24] and Equation [25] into Equation [21] yields Equation [29], which relates the subsidy or fiscal impact of full energy subsidy reform to the initial quantity consumed, the initial prices before reform, and the two elasticities.

$$S_t^{j,k} = FI_t^{j,k} = \left( P_{t,initialref}^{j,k} \frac{\omega_t^{j,k}}{\phi_t^{j,k}} \right) \left( E_{t,b}^{j,k} \frac{\tau_t^{j,k}}{\phi_t^{j,k}} + \mu_t^{j,k} \left( E_{t,b}^{j,k} - E_{t,b}^{j,k} \frac{\tau_t^{j,k}}{\phi_t^{j,k}} \right) \right) - P_{t,b}^{j,k} E_{t,b}^{j,k} + \left( P_{t,initialref}^{j,k} \frac{\omega_t^{j,k}}{\phi_t^{j,k}} - P_{t,initialref}^{j,k} \right) X_{t,initialref}^{j,k} \quad [29]$$

Further simplification yields:

$$S_t^{j,k} = FI_t^{j,k} = \left( P_{t,initialref}^{j,k} \frac{\omega_t^{j,k}}{\phi_t^{j,k}} \right) \left( \frac{\tau_t^{j,k}}{\phi_t^{j,k}} + \mu_t^{j,k} \left( 1 - \frac{\tau_t^{j,k}}{\phi_t^{j,k}} \right) \right) E_{t,b}^{j,k} - P_{t,b}^{j,k} E_{t,b}^{j,k} + \left( P_{t,initialref}^{j,k} \frac{\omega_t^{j,k}}{\phi_t^{j,k}} - P_{t,initialref}^{j,k} \right) X_{t,initialref}^{j,k} \quad [30]$$

To summarize, Equation [30] allows for the estimation of the subsidy or fiscal impact of full energy subsidy reform for any traded fuel in an energy-exporting country like Saudi Arabia, while allowing the international fuel price and domestic quantity consumed to change in response to reform. This approach results in a more realistic estimate of the fiscal impact by highlighting how a reduced international fuel price may impact the fiscal revenue of a fuel-exporting country like Saudi Arabia. It can be easily shown that if the domestic or international market responses are zero, then Equation [30] collapses into the familiar price-gap equation that I started with, which is Equation [15].

### 3.6 Data

The same IEA (2021) energy consumption data, which was used in the energy demand modelling exercise in Chapter 2, was also used for the energy subsidy reform impact analysis. Similarly, the same domestic energy price dataset that I constructed for the energy demand modelling exercise was also used.

Various sources were combined to obtain reference prices that cover all energy products in Saudi Arabia. For crude oil, Brent oil spot prices were obtained from the EIA (2024a) and used as reference prices. For oil products, including gasoline, diesel, kerosene, and LPG (specifically propane), US spot prices, also obtained from the EIA (2024b), were used as reference prices. For heavy fuel oil, US residual fuel oil wholesale prices from the EIA (2024c) were used as reference prices. For electricity, which is largely untraded, the deregulated electricity production cost from Matar and Anwer (2017), which is 0.0777 USD

per kWh, was used as the reference price. For natural gas, which is also not traded in Saudi Arabia, the marginal cost of producing non-associated gas in Saudi Arabia was used as the reference price for methane (Alyousef and Stevens, 2011), which is 4 USD per million British thermal units (mmBtu). For ethane, an additional 0.5 USD per mmBtu was added to its reference price to account for processing costs.

For the welfare analysis, Saudi-specific external costs per unit of fuel consumption were obtained from the IMF (2024), which represent updated estimates from the original study by Parry et al. (2014). However, there were some gaps in the IMF (2024) external cost data, so the following assumptions were made to extend the external cost data to all energy products in Saudi Arabia. For the consumption of crude oil and other oil products in the industrial sector, the externality is set equal to the IMF's (2024) externality for other oil products. For electricity, the IMF only provides externalities for coal use in the power sector and gas use in the power sector. However, Saudi Arabia uses both oil and gas to generate its electricity. Historically, oil has accounted for most of the Saudi power sector's fuel consumption, but the country is currently transitioning towards using more gas in its power sector (EIA, 2025b). Since the emission factors for oil tend to be somewhere between those of natural gas and coal, the externality for power generation in Saudi Arabia was estimated by taking an average of the IMF's natural gas and coal externalities for power. This average was then combined with data on the average thermal efficiency of Saudi power plants in 2018 (SEC, 2019) to approximate the externality for electricity in Saudi Arabia. For fuels used as feedstock, which do not undergo combustion but can release CO<sub>2</sub> emissions through chemical transformation processes, I follow Metcalf (2017) by assuming that one-third of the potential carbon emissions get released. I therefore set the externality associated with natural gas feedstock to be equal to one-third of the CO<sub>2</sub> externality associated with natural gas combustion in the industrial sector. For all other feedstocks, most of which are propane and butane, which are chemically similar to natural gas, I set their externality equal to that of natural gas as a feedstock.

The impact analysis also required conversion factors to convert energy quantities between different units, which were obtained from the IEA (2005). CO<sub>2</sub> emission factors were also needed to quantify the emission reductions and were obtained from the EIA (2024d).

To analyze the fiscal impacts of energy subsidy reform, additional data were needed. Annual export data for Saudi fuels were obtained from GASTAT (2022). The domestic energy demand elasticities were taken from Chapter 2, while the elasticities of the international fuel price with respect to Saudi fuel exports were informed by the range of values estimated by Karanfil and Pierru (2021) and Blazquez et al. (2020).

Karanfil and Pierru (2021) estimated the elasticity of international demand for Saudi oil exports with respect to the international oil price ( $\eta$ ) by employing a partial equilibrium framework and then deriving equations for that elasticity. Their framework positioned Saudi Arabia as a major oil producer that considers the impacts of its exports on the international oil price when making decisions on how much to export, alongside non-Saudi producers and the world as a source of demand. Karanfil and Pierru (2021) then derived an equation that linked the elasticity of international demand for Saudi oil exports with respect to the international oil price to three elasticities: 1) the global oil demand elasticity, 2) the supply elasticity of non-Saudi oil producers, and 3) the domestic price elasticity of fuel demand in Saudi Arabia. Karanfil and Pierru (2021) then calculated the elasticity of international demand for Saudi oil exports with respect to the international oil price by using estimates of those three elasticities from the literature: For the global oil demand elasticity, they obtained it from the IMF (2011a). For the supply elasticity of non-Saudi oil producers, they obtained it from Caldara et al. (2019), who used instrumental variable regressions to obtain their estimate. For the domestic demand elasticity, they used an estimate by Atalla et al. (2018), who employed the STSM to obtain their estimate, which is also the same method used in Chapter 2. By plugging these estimates from the literature into their equations, Karanfil and Pierru (2021) calculated the elasticity of demand for Saudi oil exports with respect to the international oil price to be -6.12 in the long run. Taking the inverse ( $1/\eta$ ) demonstrates that the elasticity of the international oil price with respect to Saudi oil exports is -0.16 in the long run. The value of -0.16 implies that a 10% increase in Saudi oil exports would result in a 1.6% decrease in the international oil price.

Using a general equilibrium model, Blazquez et al. (2020) estimated that a one-barrel increase in Saudi oil exports “would generate an incremental revenue equal to 79% of the international market price,” but their estimate was very specific to the context of their study.

Beyond the studies by Karanfil and Pierru (2021) and Blazquez et al. (2020), there appear to be no other estimates of the elasticity of international demand for Saudi oil exports with respect to the international oil price in the literature.

The elasticities from the literature described above were estimated specifically for Saudi oil exports. Since Saudi Arabia is a smaller exporter of refined oil products, the elasticity of the international fuel price with respect to Saudi fuel exports may be smaller for those products. To better understand the potential range of values for this elasticity across refined oil products, the ratio of Saudi crude oil exports to global crude oil consumption was compared to the corresponding ratios for oil products using Saudi export data from GASTAT (2022) and world oil consumption data from the EIA (2024e). The results are shown in Table 11, which reveals that Saudi Arabia is a larger exporter of crude oil than of refined oil products, but that its oil product exports are still generally significant. As a result, the elasticity of the international fuel price with respect to Saudi fuel exports is expected to be smaller than the value of -0.16 that was estimated by Karanfil and Pierru (2021) for crude oil specifically. Given the absence of other elasticity estimates in the literature, I present the fiscal impacts for ranges of elasticity values, which are informed by Karanfil and Pierru (2021), Blazquez et al. (2020), and the analysis in Table 11.

**Table 11** Ratio of Saudi fuel exports to global fuel consumption in 2018.

| Fuel                             | Saudi fuel exports<br>(million barrels) | World fuel<br>consumption<br>(million barrels) | Ratio |
|----------------------------------|-----------------------------------------|------------------------------------------------|-------|
| Crude oil                        | 2,693.2                                 | 36,523.7                                       | 7.4%  |
| Gasoline                         | 120.3                                   | 9,562.3                                        | 1.3%  |
| Diesel                           | 303.4                                   | 10,329.1                                       | 2.9%  |
| Kerosene (including<br>jet fuel) | 2.5                                     | 2,578.4                                        | 0.09% |
| LPG                              | 81.2                                    | 3,560.9                                        | 2.3%  |
| Fuel oil                         | 72.3                                    | 2,397.7                                        | 3.0%  |

*Note: World crude oil consumption was obtained from the EIA (2024e) using the data point for world consumption of refined petroleum products, which includes the world consumption of gasoline, kerosene (including jet fuel), diesel, fuel oil, LPG, and other petroleum liquids.*

## 3.7 Results

### 3.7.1 Welfare impact analysis results

Using my estimated price elasticities from Chapter 2, I quantify the actual impacts of implemented energy subsidy reforms in Saudi Arabia and the potential impacts of further reforms if they were to be implemented. My analysis is done using both short- and long-run price elasticities. Since the long-run elasticities are generally larger, the welfare gains are also larger in the long run. (A larger price elasticity implies a stronger consumer response, which in turn implies that the provision of a subsidy leads to a larger increase in inefficient or wasteful energy consumption.) In the discussion that follows, although both sets of results are presented, only the long-run results are discussed.

The welfare analysis rests on comparing deadweight loss and external costs (and the sum of the two, which represents the total welfare change) between pairs of scenarios. To measure the actual impacts of the implemented partial reforms, I compare the deadweight loss and external costs in the actual scenario, in which energy prices were partially reformed

by the Saudi government in 2016 and 2018, to a counterfactual baseline scenario in which domestic energy prices were never reformed and continued at their 2015 nominal price levels (see Table 12). To measure the potential impacts of further reform, I compare the deadweight loss and external costs of the actual scenario to another counterfactual scenario in which domestic energy prices are fully reformed and set equal to their reference prices in each year (see Table 13). I conduct this welfare analysis for each energy product in each end-use sector for each year between 2016 and 2018. For energy products with no estimated final models, I use the elasticities from the estimated total/aggregate sectoral models to ensure complete coverage.

**Table 12** *Illustrative gasoline prices across the two scenarios used to analyze the actual impacts of the implemented partial energy subsidy reforms.*

|                                                                                            | Year | Nominal 91-octane gasoline price in SR per litre (used for scenario illustration) |
|--------------------------------------------------------------------------------------------|------|-----------------------------------------------------------------------------------|
| <b>Actual scenario:</b><br>partial energy price reforms implemented in 2016 and 2018       | 2015 | 0.45                                                                              |
|                                                                                            | 2016 | 0.75                                                                              |
|                                                                                            | 2017 | 0.75                                                                              |
|                                                                                            | 2018 | 1.37                                                                              |
| <b>Counterfactual baseline scenario:</b><br>partial energy price reforms never implemented | 2015 | 0.45                                                                              |
|                                                                                            | 2016 | 0.45                                                                              |
|                                                                                            | 2017 | 0.45                                                                              |
|                                                                                            | 2018 | 0.45 + 5% VAT                                                                     |

*Notes: SR = Saudi Riyal; VAT = value added tax. The 91-octane gasoline price is used for scenario illustration. The same approach is applied to the prices of all energy products under each scenario. The actual 2018 prices include the 5% VAT, which was also added to the prices in 2018 under the counterfactual scenario. Sources of energy prices discussed in section 2.4.*

**Table 13** Illustrative gasoline prices across the two scenarios used to analyze the potential impacts of future full energy subsidy reforms

|                                                                                                | Year | Nominal 95-octane gasoline price in SR per litre (used for scenario illustration) |
|------------------------------------------------------------------------------------------------|------|-----------------------------------------------------------------------------------|
| <b>Actual scenario:</b><br>partial energy price reforms implemented in 2016 and 2018           | 2015 | 0.45                                                                              |
|                                                                                                | 2016 | 0.75                                                                              |
|                                                                                                | 2017 | 0.75                                                                              |
|                                                                                                | 2018 | 1.37                                                                              |
| <b>Counterfactual full reform scenario:</b><br>full energy price reforms implemented each year | 2015 | 1.60                                                                              |
|                                                                                                | 2016 | 1.38                                                                              |
|                                                                                                | 2017 | 1.62                                                                              |
|                                                                                                | 2018 | 1.91 + 5% VAT                                                                     |

*Notes: SR = Saudi Riyal; VAT = value added tax. The 91-octane gasoline price is used for scenario illustration. The same approach is applied to the prices of all energy products under each scenario. The actual 2018 prices include the 5% VAT, which was also added to the prices in 2018 under the counterfactual scenario. Sources of energy prices discussed in sections 2.4 and 3.6.*

I find significant gains from the two partial waves of energy subsidy reform implemented by the Saudi government in 2016 and 2018 (see Table 14). My long-run analysis reveals that the 2016 reform delivered a total reduction in deadweight loss of around 3.4 billion 2010 USD in that year. Moreover, it delivered a 10.6 billion 2010 USD reduction in external costs. Summing both reductions yields the total welfare gain, at 14.0 billion 2010 USD<sup>11</sup>, with diesel for transport accounting for the largest share, followed by industrial fuel oil, transport gasoline, and industrial natural gas. The total welfare gain increased slightly in 2017, to 15.9

<sup>11</sup> Numbers may not always sum up due to rounding.

billion 2010 USD, even though domestic energy prices did not change between 2016 and 2017.<sup>12</sup> In 2018, as the second wave of energy subsidy reform took place, the total welfare gain jumped to 21.9 billion 2010 USD, as the welfare analysis picks up the combined impacts of both the 2016 and 2018 reforms. This total welfare gain in 2018 represents around 3% of real Saudi GDP in that year and is made up of a 6.4 billion 2010 USD reduction in deadweight loss and a 15.4 billion 2010 USD reduction in external costs.

The welfare gains for each energy product in each sector depend on several factors. One important factor is the quantity of energy consumed. The greater the consumption of an energy product, the larger the welfare gain from energy subsidy reform, which explains why the welfare gains are larger for gasoline and diesel in the transport sector and natural gas and fuel oil in the industrial sector. The size of the price increase is another crucial factor, as larger price increases result in larger welfare gains. In 2018, the price increases were largest on residential electricity and gasoline, explaining the larger increases in welfare associated with both energy products in 2018. The size of the price elasticity also plays an essential role: the more elastic demand is for a product, the bigger the welfare gain from energy subsidy reform. Finally, the per-unit external cost estimates also influence the size of the reductions in external costs and thus the size of the welfare gains. Larger negative externalities yield larger welfare gains from energy subsidy reform.

The welfare results are in line with a few previously published results. For example, Atalla et al. (2018) measured the welfare gain from the 2016 gasoline price reform to be 1.7 billion 2010 USD, only a bit smaller than my estimated value of 2.2 billion 2010 USD. The difference is likely due to my larger price elasticity (Atalla et al.'s estimation period ended in 2015) and the updated per-unit external cost estimates used in this thesis. In contrast, Aldubyan and Gasim (2021) estimated the welfare gain due to the 2018 wave of gasoline price reform to be 2.3 billion 2010 USD, while I estimated a welfare gain of 6.1 billion 2010 USD. However, my welfare calculation for 2018 captures the combined welfare gain due to both the 2016 and 2018 gasoline price increases.

---

<sup>12</sup> While domestic energy prices in 2017 were the same as in 2016, the quantity of energy consumed, the energy products' reference prices, and the size of the associated externalities vary year to year, affecting the annual welfare calculations.

I also demonstrate that greater welfare gains could have been realized if further energy subsidy reforms were implemented in the past, until domestic prices were 100% equal to reference prices in each year (see Table 14). I find that in 2016, further energy subsidy reform could have resulted in an additional 3.7 billion 2010 USD reduction in deadweight loss and an 18.9 billion 2010 USD reduction in externalities, yielding a potential total welfare gain of 22.6 billion 2010 USD. (This gain is calculated by comparing the actual scenario of 2016 partially reformed prices to a counterfactual scenario in which prices were fully reformed in 2016.) In 2018, despite the implementation of a second wave of partial reform, further energy subsidy reform in that year could have resulted in a 6.5 billion 2010 USD reduction in deadweight loss and a 24.2 billion 2010 USD reduction in externalities, yielding a potential total welfare gain of 30.7 billion 2010 USD. (This gain is calculated by comparing the actual scenario of 2018 partially reformed prices to a counterfactual scenario in which prices were fully reformed in 2018.) Despite domestic energy prices in 2018 being higher than in 2016, the potential welfare gains from further reforms were larger in 2018 as international oil prices were also relatively higher, increasing the gap between reference and actual domestic prices in 2018 in the welfare calculations. Furthermore, per-unit externality estimates by the IMF, which were inputs to the analysis, also increased in 2018. In summary, my analysis shows that although significant welfare gains have already been achieved through past energy subsidy reforms, there remain even larger welfare gains to be unlocked through further reforms. However, further increases in energy prices will likely be politically challenging to implement.

Table 15 shows the results using the short-run elasticities. On average, the welfare gains from the short-run analysis appear to be 70%-80% of the size of the welfare gains from the long-run analysis, suggesting that most of the gains can be achieved relatively quickly.

The energy price increases, and their associated welfare impacts, varied across energy products between the 2016 and 2018 waves of energy subsidy reform, raising an interesting question about the optimal rate of reform. Looking at it from the simple perspective of maximizing social welfare, fully removing energy subsidies in 2016 would have been the optimal decision. However, this does not consider other important factors, such as political feasibility and the pain consumers and businesses would face in the

short-term as they adjust to such a shock. This explains why the Saudi government adopted a phased approach to energy subsidy reform. The Saudi government likely had to strike a balance between energy subsidy reform's fiscal gains, their negative impacts on households, and their negative impacts on industrial competitiveness. These factors likely influenced when each wave of energy subsidy reform was implemented, which energy products were targeted, and how large the energy price increases were. Furthermore, to maximize the welfare gains from its phased approach, the Saudi government may have also considered the relative importance of each energy product and the potential fiscal and economic gains from its reform. The first wave of energy subsidy reform in 2016 targeted all energy products, including those in the transport, industrial, and residential sectors, without compensation or mitigation mechanisms. Although the energy price increases in 2016 were large in percentage terms, they were implemented on relatively low energy price levels. This likely reduced the need for compensation mechanisms, which also take time to design. Furthermore, the large budget deficit recorded in 2015 (SAMA, 2020) following the collapse in international oil prices probably necessitated quick fiscal action to raise government revenue. The second wave of energy subsidy reform in 2018 appeared to target energy products used by households and was implemented only after the launch of the Citizen's Account program to compensate eligible households (Arab News, 2017; Fiscal Balance Program, 2018). The Saudi government appears to have had more time to prepare for the 2018 reform, allowing it to design and launch its comprehensive compensation scheme. The scheme allowed the Saudi government to again implement large energy price increases in percentage terms, especially on household energy products like gasoline and residential electricity. Furthermore, unlike in 2016, the energy price increases in 2018 were implemented on relatively higher energy price levels, likely making them appear more significant from the perspective of households. On the other hand, the energy price increases in 2018 on industrial fuels were limited, presumably because there was no mechanism yet to mitigate the negative impacts on industrial competitiveness. However, since then, the government has continued to implement minor gradual energy price increases, with recent reforms in 2024 and 2025 affecting some industrial fuel and feedstock prices (Riyad Capital, 2024; Arab News, 2025; Aljazira Capital, 2025).

**Table 14** The actual and potential welfare impacts of energy subsidy reform using the long-run price elasticities.

Notes: All monetary values in units of billion 2010 USD.

| End-use sector:<br>Energy product    | Actual impacts of implemented energy subsidy reforms<br>(moving from pre-reform prices to baseline reformed prices) |            |            |                               |             |             |                    |             |             | Potential impacts of further energy subsidy reforms<br>(moving from baseline reformed prices to fully reformed prices) |            |            |                               |             |             |                    |             |             |
|--------------------------------------|---------------------------------------------------------------------------------------------------------------------|------------|------------|-------------------------------|-------------|-------------|--------------------|-------------|-------------|------------------------------------------------------------------------------------------------------------------------|------------|------------|-------------------------------|-------------|-------------|--------------------|-------------|-------------|
|                                      | Reduction in<br>deadweight loss                                                                                     |            |            | Reduction in<br>externalities |             |             | Total welfare gain |             |             | Reduction in<br>deadweight loss                                                                                        |            |            | Reduction in<br>externalities |             |             | Total welfare gain |             |             |
|                                      | 2016                                                                                                                | 2017       | 2018       | 2016                          | 2017        | 2018        | 2016               | 2017        | 2018        | 2016                                                                                                                   | 2017       | 2018       | 2016                          | 2017        | 2018        | 2016               | 2017        | 2018        |
| <b>Transport</b>                     |                                                                                                                     |            |            |                               |             |             |                    |             |             |                                                                                                                        |            |            |                               |             |             |                    |             |             |
| Gasoline                             | 0.4                                                                                                                 | 0.6        | 1.4        | 1.8                           | 2.0         | 4.7         | 2.2                | 2.6         | 6.1         | 0.2                                                                                                                    | 0.4        | 0.1        | 2.1                           | 3.0         | 1.3         | 2.3                | 3.4         | 1.4         |
| Diesel                               | 1.1                                                                                                                 | 1.3        | 1.7        | 4.5                           | 4.5         | 4.5         | 5.6                | 5.9         | 6.3         | 0.9                                                                                                                    | 1.3        | 2.1        | 6.6                           | 7.6         | 8.9         | 7.4                | 8.9         | 11.0        |
| Kerosene                             | 0.0                                                                                                                 | 0.0        | 0.0        | 0.0                           | 0.0         | 0.0         | 0.0                | 0.0         | 0.0         | 0.0                                                                                                                    | 0.0        | 0.0        | 0.0                           | 0.0         | 0.0         | 0.0                | 0.1         | 0.1         |
| <b>Residential</b>                   |                                                                                                                     |            |            |                               |             |             |                    |             |             |                                                                                                                        |            |            |                               |             |             |                    |             |             |
| LPG                                  | 0.0                                                                                                                 | 0.0        | 0.0        | 0.0                           | 0.0         | 0.0         | 0.0                | 0.0         | 0.0         | 0.0                                                                                                                    | 0.0        | 0.0        | 0.0                           | 0.0         | 0.0         | 0.0                | 0.0         | 0.0         |
| Electricity                          | 0.1                                                                                                                 | 0.1        | 0.7        | 0.1                           | 0.1         | 0.9         | 0.2                | 0.2         | 1.6         | 1.0                                                                                                                    | 1.1        | 0.4        | 1.6                           | 1.8         | 0.5         | 1.0                | 1.1         | 0.4         |
| <b>Commercial &amp; governmental</b> |                                                                                                                     |            |            |                               |             |             |                    |             |             |                                                                                                                        |            |            |                               |             |             |                    |             |             |
| Electricity                          | 0.0                                                                                                                 | 0.0        | 0.0        | 0.1                           | 0.1         | 0.1         | 0.1                | 0.1         | 0.2         | 0.0                                                                                                                    | 0.1        | 0.0        | 0.0                           | 0.1         | 0.0         | 0.0                | 0.1         | 0.0         |
| <b>Industrial</b>                    |                                                                                                                     |            |            |                               |             |             |                    |             |             |                                                                                                                        |            |            |                               |             |             |                    |             |             |
| Natural gas                          | 0.8                                                                                                                 | 0.7        | 0.8        | 1.1                           | 1.1         | 1.2         | 2.0                | 1.8         | 2.0         | 1.6                                                                                                                    | 1.5        | 1.7        | 2.3                           | 2.1         | 2.3         | 1.6                | 1.5         | 1.7         |
| Crude oil                            | 0.1                                                                                                                 | 0.0        | 0.0        | 0.2                           | 0.1         | 0.1         | 0.2                | 0.1         | 0.1         | 0.7                                                                                                                    | 0.3        | 0.3        | 0.8                           | 0.4         | 0.5         | 0.7                | 0.3         | 0.3         |
| Diesel                               | 0.1                                                                                                                 | 0.1        | 0.1        | 0.2                           | 0.2         | 0.2         | 0.2                | 0.2         | 0.2         | 0.5                                                                                                                    | 0.5        | 0.5        | 0.6                           | 0.7         | 0.6         | 0.5                | 0.5         | 0.5         |
| Heavy fuel oil                       | 0.5                                                                                                                 | 1.0        | 1.3        | 2.4                           | 3.5         | 3.5         | 2.9                | 4.5         | 4.8         | 6.2                                                                                                                    | 10.1       | 10.9       | 7.1                           | 12.2        | 13.9        | 6.2                | 10.1        | 10.9        |
| Electricity                          | 0.1                                                                                                                 | 0.1        | 0.1        | 0.1                           | 0.1         | 0.1         | 0.1                | 0.2         | 0.2         | 0.1                                                                                                                    | 0.1        | 0.2        | 0.2                           | 0.2         | 0.2         | 0.1                | 0.1         | 0.2         |
| <b>Feedstock / non-energy use</b>    |                                                                                                                     |            |            |                               |             |             |                    |             |             |                                                                                                                        |            |            |                               |             |             |                    |             |             |
| Natural gas                          | 0.0                                                                                                                 | 0.0        | 0.0        | 0.0                           | 0.0         | 0.0         | 0.0                | 0.0         | 0.0         | 0.0                                                                                                                    | 0.0        | 0.0        | 0.0                           | 0.0         | 0.0         | 0.0                | 0.0         | 0.0         |
| Ethane                               | 0.2                                                                                                                 | 0.2        | 0.2        | 0.1                           | 0.1         | 0.1         | 0.3                | 0.3         | 0.3         | 0.1                                                                                                                    | 0.1        | 0.1        | 0.2                           | 0.2         | 0.2         | 0.1                | 0.1         | 0.1         |
| LPG                                  | 0.0                                                                                                                 | 0.0        | 0.0        | 0.0                           | 0.0         | 0.0         | 0.0                | 0.0         | 0.0         | 0.0                                                                                                                    | 0.0        | 0.0        | 0.0                           | 0.0         | 0.0         | 0.0                | 0.0         | 0.0         |
| Naphtha                              | 0.0                                                                                                                 | 0.0        | 0.0        | 0.0                           | 0.0         | 0.0         | 0.0                | 0.0         | 0.0         | 0.0                                                                                                                    | 0.0        | 0.0        | 0.0                           | 0.0         | 0.0         | 0.0                | 0.0         | 0.0         |
| <b>Totals</b>                        | <b>3.4</b>                                                                                                          | <b>4.1</b> | <b>6.4</b> | <b>10.6</b>                   | <b>11.8</b> | <b>15.4</b> | <b>14.0</b>        | <b>15.9</b> | <b>21.9</b> | <b>3.7</b>                                                                                                             | <b>5.4</b> | <b>6.5</b> | <b>18.9</b>                   | <b>24.5</b> | <b>24.2</b> | <b>22.6</b>        | <b>29.9</b> | <b>30.7</b> |

**Table 15** The actual and potential welfare impacts of energy subsidy reform using the short-run price elasticities.

Notes: All monetary values in units of billion 2010 USD.

| End-use sector:<br>Energy product    | Actual impacts of implemented energy subsidy reforms<br>(moving from pre-reform prices to baseline reformed prices) |            |            |                               |            |             |                    |             |             | Potential impacts of further energy subsidy reforms<br>(moving from baseline reformed prices to fully reformed prices) |            |            |                               |             |             |                    |             |             |
|--------------------------------------|---------------------------------------------------------------------------------------------------------------------|------------|------------|-------------------------------|------------|-------------|--------------------|-------------|-------------|------------------------------------------------------------------------------------------------------------------------|------------|------------|-------------------------------|-------------|-------------|--------------------|-------------|-------------|
|                                      | Reduction in<br>deadweight loss                                                                                     |            |            | Reduction in<br>externalities |            |             | Total welfare gain |             |             | Reduction in<br>deadweight loss                                                                                        |            |            | Reduction in<br>externalities |             |             | Total welfare gain |             |             |
|                                      | 2016                                                                                                                | 2017       | 2018       | 2016                          | 2017       | 2018        | 2016               | 2017        | 2018        | 2016                                                                                                                   | 2017       | 2018       | 2016                          | 2017        | 2018        | 2016               | 2017        | 2018        |
| <b>Transport</b>                     |                                                                                                                     |            |            |                               |            |             |                    |             |             |                                                                                                                        |            |            |                               |             |             |                    |             |             |
| Gasoline                             | 0.3                                                                                                                 | 0.4        | 1.0        | 1.3                           | 1.5        | 3.4         | 1.6                | 1.9         | 4.4         | 0.2                                                                                                                    | 0.3        | 0.1        | 1.5                           | 2.2         | 0.9         | 1.7                | 2.5         | 1.0         |
| Diesel                               | 1.0                                                                                                                 | 1.2        | 1.6        | 4.1                           | 4.2        | 4.2         | 5.2                | 5.4         | 5.8         | 0.8                                                                                                                    | 1.2        | 2.0        | 6.2                           | 7.2         | 8.4         | 7.0                | 8.4         | 10.3        |
| Kerosene                             | 0.0                                                                                                                 | 0.0        | 0.0        | 0.0                           | 0.0        | 0.0         | 0.0                | 0.0         | 0.0         | 0.0                                                                                                                    | 0.0        | 0.0        | 0.0                           | 0.0         | 0.0         | 0.0                | 0.1         | 0.1         |
| <b>Residential</b>                   |                                                                                                                     |            |            |                               |            |             |                    |             |             |                                                                                                                        |            |            |                               |             |             |                    |             |             |
| LPG                                  | 0.0                                                                                                                 | 0.0        | 0.0        | 0.0                           | 0.0        | 0.0         | 0.0                | 0.0         | 0.0         | 0.0                                                                                                                    | 0.0        | 0.0        | 0.0                           | 0.0         | 0.0         | 0.0                | 0.0         | 0.0         |
| Electricity                          | 0.1                                                                                                                 | 0.1        | 0.7        | 0.1                           | 0.1        | 0.9         | 0.2                | 0.2         | 1.6         | 0.7                                                                                                                    | 0.7        | 0.1        | 1.0                           | 1.1         | 0.4         | 1.6                | 1.8         | 0.5         |
| <b>Commercial &amp; governmental</b> |                                                                                                                     |            |            |                               |            |             |                    |             |             |                                                                                                                        |            |            |                               |             |             |                    |             |             |
| Electricity                          | 0.0                                                                                                                 | 0.0        | 0.0        | 0.0                           | 0.0        | 0.0         | 0.0                | 0.0         | 0.0         | 0.0                                                                                                                    | 0.0        | 0.0        | 0.0                           | 0.0         | 0.0         | 0.0                | 0.0         | 0.0         |
| <b>Industrial</b>                    |                                                                                                                     |            |            |                               |            |             |                    |             |             |                                                                                                                        |            |            |                               |             |             |                    |             |             |
| Natural gas                          | 1.1                                                                                                                 | 0.9        | 1.0        | 1.5                           | 1.4        | 1.6         | 2.6                | 2.4         | 2.6         | 0.8                                                                                                                    | 0.7        | 0.8        | 1.9                           | 1.8         | 2.0         | 2.7                | 2.4         | 2.7         |
| Crude oil                            | 0.0                                                                                                                 | 0.0        | 0.0        | 0.1                           | 0.0        | 0.0         | 0.1                | 0.0         | 0.1         | 0.1                                                                                                                    | 0.0        | 0.1        | 0.4                           | 0.2         | 0.2         | 0.4                | 0.2         | 0.3         |
| Diesel                               | 0.1                                                                                                                 | 0.1        | 0.1        | 0.2                           | 0.2        | 0.2         | 0.2                | 0.2         | 0.2         | 0.1                                                                                                                    | 0.1        | 0.1        | 0.5                           | 0.5         | 0.5         | 0.6                | 0.7         | 0.6         |
| Heavy fuel oil                       | 0.2                                                                                                                 | 0.4        | 0.6        | 0.0                           | 1.6        | 1.6         | 0.2                | 2.0         | 2.2         | 0.5                                                                                                                    | 1.1        | 1.7        | 3.5                           | 5.8         | 6.3         | 3.9                | 6.9         | 8.0         |
| Electricity                          | 0.1                                                                                                                 | 0.1        | 0.1        | 0.0                           | 0.1        | 0.1         | 0.1                | 0.2         | 0.2         | 0.0                                                                                                                    | 0.0        | 0.0        | 0.1                           | 0.1         | 0.2         | 0.2                | 0.2         | 0.2         |
| <b>Feedstock / non-energy use</b>    |                                                                                                                     |            |            |                               |            |             |                    |             |             |                                                                                                                        |            |            |                               |             |             |                    |             |             |
| Natural gas                          | 0.0                                                                                                                 | 0.0        | 0.0        | 0.0                           | 0.0        | 0.0         | 0.0                | 0.0         | 0.0         | 0.0                                                                                                                    | 0.0        | 0.0        | 0.0                           | 0.0         | 0.0         | 0.0                | 0.0         | 0.0         |
| Ethane                               | 0.0                                                                                                                 | 0.0        | 0.0        | 0.0                           | 0.0        | 0.0         | 0.0                | 0.0         | 0.0         | 0.0                                                                                                                    | 0.0        | 0.0        | 0.0                           | 0.0         | 0.0         | 0.0                | 0.0         | 0.0         |
| LPG                                  | 0.0                                                                                                                 | 0.0        | 0.0        | 0.0                           | 0.0        | 0.0         | 0.0                | 0.0         | 0.0         | 0.0                                                                                                                    | 0.0        | 0.0        | 0.0                           | 0.0         | 0.0         | 0.0                | 0.0         | 0.0         |
| Naphtha                              | 0.0                                                                                                                 | 0.0        | 0.0        | 0.0                           | 0.0        | 0.0         | 0.0                | 0.0         | 0.0         | 0.0                                                                                                                    | 0.0        | 0.0        | 0.0                           | 0.0         | 0.0         | 0.0                | 0.0         | 0.0         |
| <b>Totals</b>                        | <b>2.9</b>                                                                                                          | <b>3.3</b> | <b>5.2</b> | <b>7.4</b>                    | <b>9.1</b> | <b>12.0</b> | <b>10.3</b>        | <b>12.4</b> | <b>17.1</b> | <b>3.1</b>                                                                                                             | <b>4.3</b> | <b>4.9</b> | <b>15.0</b>                   | <b>18.9</b> | <b>18.9</b> | <b>18.2</b>        | <b>23.2</b> | <b>23.8</b> |

### 3.7.2 Emission impact analysis results

My analysis reveals that the 2016 and 2018 waves of energy subsidy reform delivered significant reductions in CO<sub>2</sub> emissions, as shown in Table 16. Using the long-run price elasticities, I find that the 2016 reform delivered 51.3 Mt of avoided CO<sub>2</sub> emissions annually. This value fell slightly to 49.6 Mt in 2017, before rising to 66.5 Mt in 2018 as the second reform ensued. The avoided emissions in 2018, due to the combined effect of both waves of subsidy reform, represented around 11% of actual energy-related CO<sub>2</sub> emissions in Saudi Arabia in that year (BP, 2020). They also represent almost one-half of the original target Saudi Arabia had submitted in 2015 for its first NDC, when it had announced its aim "to achieve mitigation co-benefits ambitions of up to 130 million tons of CO<sub>2</sub>eq avoided by 2030 annually" (Kingdom of Saudi Arabia, 2015).

My analysis also highlights the potential contributions of further energy subsidy reforms. In 2021, Saudi Arabia updated its NDC, increasing its target from 130 to 278 MtCO<sub>2</sub>eq of avoided emissions annually by 2030 (Kingdom of Saudi Arabia, 2021). My analysis reveals that had Saudi Arabia implemented further reforms in 2016, until all domestic energy prices were 100% equal to reference prices in that year, then it could have unlocked an additional 93.0 Mt of avoided CO<sub>2</sub> emissions in 2016. This value would have grown to 102.6 Mt in 2017, before falling to 94.9 Mt in 2018, as the implementation of the second wave of partial reform in 2018 absorbs some of the potential reductions that are possible from full reform. My results thus demonstrate that fully reforming domestic energy subsidies could have been enough to meet Saudi Arabia's first NDC target, but that full energy subsidy reform alone (using 2018 reference prices for example) would only have delivered about one-third of the updated NDC target. Although the avoided emissions due to full energy subsidy reform will likely grow as domestic energy consumption increases, my analysis suggests that policymakers in Saudi Arabia will need to explore other policies in addition to energy subsidy reform to achieve their climate targets.<sup>13</sup>

Table 17 shows the results using the short-run elasticities. On average, the emission reductions from the short-run analysis appear to be between 80% and 90% of the size of the reductions estimated using the long-run elasticities, suggesting that most of the

---

<sup>13</sup> While the main driver of energy subsidy reform in Saudi Arabia has been fiscal, the resource sustainability and climate change mitigation co-benefits appear to be becoming increasingly important.

environmental gains from energy subsidy reform in Saudi Arabia can be achieved relatively quickly.

My estimates of avoided emissions are also sensitive to the reference prices. In 2018, international fuel prices were relatively low. For example, the Brent oil spot price was 71.3 USD per barrel, while in 2022 it was 100.9 USD per barrel. Full energy subsidy reform, using 2022 reference prices and 2018 energy consumption quantities, would have resulted in 110.7 Mt of avoided CO<sub>2</sub> emissions in that year, compared to a value of 94.9 Mt using 2018 reference prices. In conclusion, higher international fuel prices will increase the gap between domestic prices and reference prices, thereby allowing energy subsidy reform to generate greater emission reductions. In contrast, lower international fuel prices will reduce the potential emission reductions that can be achieved through subsidy removal.

**Table 16** *The annual avoided CO<sub>2</sub> emissions (in million tonnes) from actual and potential energy subsidy reforms using the long-run price elasticities.*

| <b>End-use sector:<br/>Energy product</b> | <b>Actual CO<sub>2</sub> emissions avoided due to<br/>implemented subsidy reforms<br/>(moving from pre-reform prices to baseline<br/>reformed prices)</b> |             |             | <b>Potential CO<sub>2</sub> emissions avoided by<br/>further subsidy reforms<br/>(moving from baseline reformed prices to fully<br/>reformed prices)</b> |              |             |
|-------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|-------------|----------------------------------------------------------------------------------------------------------------------------------------------------------|--------------|-------------|
|                                           | <b>2016</b>                                                                                                                                               | <b>2017</b> | <b>2018</b> | <b>2016</b>                                                                                                                                              | <b>2017</b>  | <b>2018</b> |
| <b>Transport:</b>                         |                                                                                                                                                           |             |             |                                                                                                                                                          |              |             |
| Gasoline                                  | 5.7                                                                                                                                                       | 5.8         | 13.0        | 6.5                                                                                                                                                      | 8.5          | 3.5         |
| Diesel                                    | 12.8                                                                                                                                                      | 11.9        | 11.4        | 18.8                                                                                                                                                     | 20.0         | 22.4        |
| Kerosene                                  | 0.2                                                                                                                                                       | 0.2         | 0.2         | 0.4                                                                                                                                                      | 0.5          | 0.5         |
| <b>Residential:</b>                       |                                                                                                                                                           |             |             |                                                                                                                                                          |              |             |
| LPG                                       | 0.0                                                                                                                                                       | 0.0         | 0.0         | -0.2                                                                                                                                                     | 0.0          | 0.1         |
| Electricity                               | 1.5                                                                                                                                                       | 1.1         | 9.7         | 12.7                                                                                                                                                     | 13.0         | 4.6         |
| <b>Commercial &amp; governmental:</b>     |                                                                                                                                                           |             |             |                                                                                                                                                          |              |             |
| Electricity                               | 1.1                                                                                                                                                       | 1.1         | 1.4         | 0.6                                                                                                                                                      | 0.6          | 0.4         |
| <b>Industrial:</b>                        |                                                                                                                                                           |             |             |                                                                                                                                                          |              |             |
| Natural gas                               | 17.0                                                                                                                                                      | 14.1        | 15.5        | 23.7                                                                                                                                                     | 19.6         | 21.7        |
| Crude oil                                 | 0.7                                                                                                                                                       | 0.3         | 0.3         | 2.4                                                                                                                                                      | 1.0          | 1.1         |
| Diesel                                    | 0.6                                                                                                                                                       | 0.5         | 0.5         | 1.9                                                                                                                                                      | 1.8          | 1.5         |
| Heavy fuel oil                            | 9.1                                                                                                                                                       | 12.0        | 11.6        | 23.4                                                                                                                                                     | 34.5         | 35.7        |
| Electricity                               | 1.1                                                                                                                                                       | 1.1         | 1.2         | 1.5                                                                                                                                                      | 1.6          | 1.7         |
| <b>Non-energy (feedstock):</b>            |                                                                                                                                                           |             |             |                                                                                                                                                          |              |             |
| Natural gas                               | 0.1                                                                                                                                                       | 0.1         | 0.1         | 0.2                                                                                                                                                      | 0.2          | 0.2         |
| Ethane                                    | 1.3                                                                                                                                                       | 1.4         | 1.4         | 1.3                                                                                                                                                      | 1.3          | 1.4         |
| LPG                                       | 0.0                                                                                                                                                       | 0.1         | 0.0         | -0.1                                                                                                                                                     | 0.0          | 0.0         |
| Naphtha                                   | 0.1                                                                                                                                                       | 0.1         | 0.1         | -0.2                                                                                                                                                     | 0.0          | 0.0         |
| <b>Total</b>                              | <b>51.3</b>                                                                                                                                               | <b>49.6</b> | <b>66.5</b> | <b>93.0</b>                                                                                                                                              | <b>102.6</b> | <b>94.9</b> |

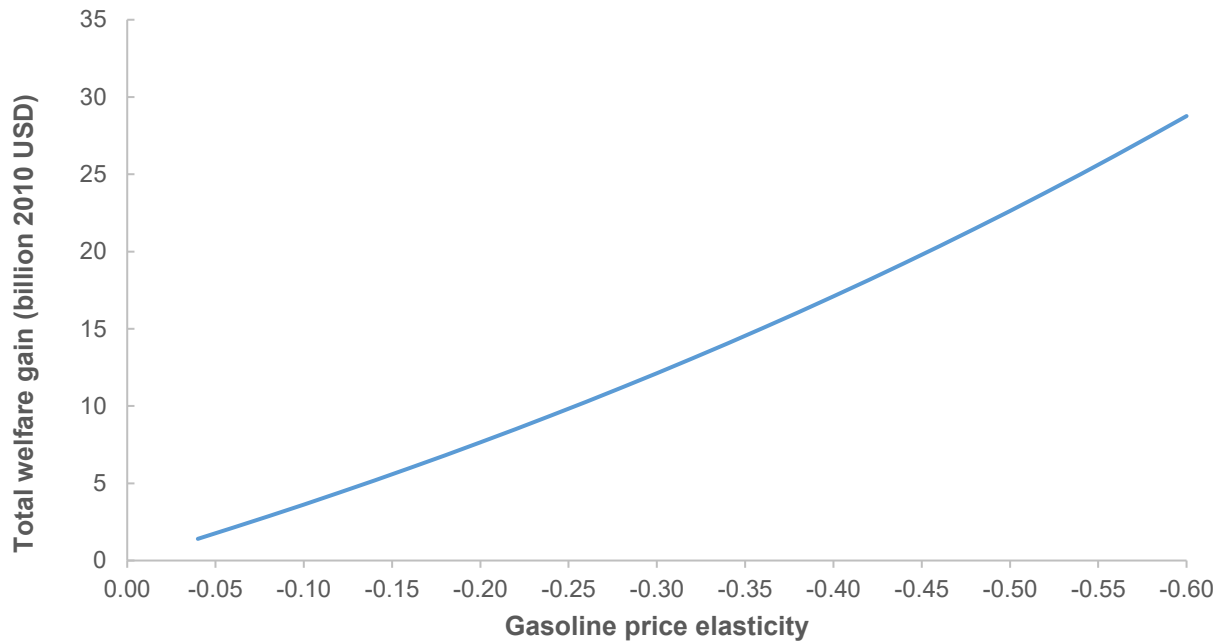
**Table 17** The annual avoided CO<sub>2</sub> emissions (in million tonnes) from actual and potential energy subsidy reforms using the short-run price elasticities.

| <i>End-use sector:<br/>Energy product</i> | <b>Actual CO<sub>2</sub> emissions avoided due to implemented subsidy reforms</b><br>(moving from pre-reform prices to baseline reformed prices) |             |             | <b>Potential CO<sub>2</sub> emissions avoided by further subsidy reforms</b><br>(moving from baseline reformed prices to fully reformed prices) |             |             |
|-------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------|-------------|-------------|-------------------------------------------------------------------------------------------------------------------------------------------------|-------------|-------------|
|                                           | 2016                                                                                                                                             | 2017        | 2018        | 2016                                                                                                                                            | 2017        | 2018        |
| <b>Transport:</b>                         |                                                                                                                                                  |             |             |                                                                                                                                                 |             |             |
| Gasoline                                  | 4.2                                                                                                                                              | 4.3         | 9.4         | 4.9                                                                                                                                             | 6.3         | 2.6         |
| Diesel                                    | 11.9                                                                                                                                             | 11.0        | 10.6        | 17.7                                                                                                                                            | 18.8        | 21.1        |
| Kerosene                                  | 0.2                                                                                                                                              | 0.2         | 0.2         | 0.4                                                                                                                                             | 0.5         | 0.5         |
| <b>Residential:</b>                       |                                                                                                                                                  |             |             |                                                                                                                                                 |             |             |
| LPG                                       | 0.0                                                                                                                                              | 0.0         | 0.0         | -0.2                                                                                                                                            | 0.0         | 0.1         |
| Electricity                               | 1.5                                                                                                                                              | 1.1         | 9.7         | 12.7                                                                                                                                            | 13.0        | 4.6         |
| <b>Commercial &amp; governmental:</b>     |                                                                                                                                                  |             |             |                                                                                                                                                 |             |             |
| Electricity                               | 0.0                                                                                                                                              | 0.0         | 0.0         | 0.0                                                                                                                                             | 0.0         | 0.0         |
| <b>Industrial:</b>                        |                                                                                                                                                  |             |             |                                                                                                                                                 |             |             |
| Natural gas                               | 22.6                                                                                                                                             | 18.7        | 20.6        | 27.7                                                                                                                                            | 23.0        | 25.4        |
| Crude oil                                 | 0.3                                                                                                                                              | 0.1         | 0.1         | 1.3                                                                                                                                             | 0.6         | 0.6         |
| Diesel                                    | 0.6                                                                                                                                              | 0.5         | 0.5         | 1.9                                                                                                                                             | 1.8         | 1.5         |
| Heavy fuel oil                            | 4.1                                                                                                                                              | 5.4         | 5.3         | 13.0                                                                                                                                            | 19.7        | 20.7        |
| Electricity                               | 1.1                                                                                                                                              | 1.1         | 1.2         | 1.5                                                                                                                                             | 1.6         | 1.7         |
| <b>Non-energy (feedstock):</b>            |                                                                                                                                                  |             |             |                                                                                                                                                 |             |             |
| Natural gas                               | 0.0                                                                                                                                              | 0.0         | 0.0         | 0.0                                                                                                                                             | 0.0         | 0.0         |
| Ethane                                    | 0.0                                                                                                                                              | 0.0         | 0.0         | 0.0                                                                                                                                             | 0.0         | 0.0         |
| LPG                                       | 0.0                                                                                                                                              | 0.1         | 0.0         | -0.1                                                                                                                                            | 0.0         | 0.0         |
| Naphtha                                   | 0.1                                                                                                                                              | 0.1         | 0.1         | -0.2                                                                                                                                            | 0.0         | 0.0         |
| <b>Total</b>                              | <b>46.5</b>                                                                                                                                      | <b>42.5</b> | <b>57.6</b> | <b>80.6</b>                                                                                                                                     | <b>85.2</b> | <b>78.9</b> |

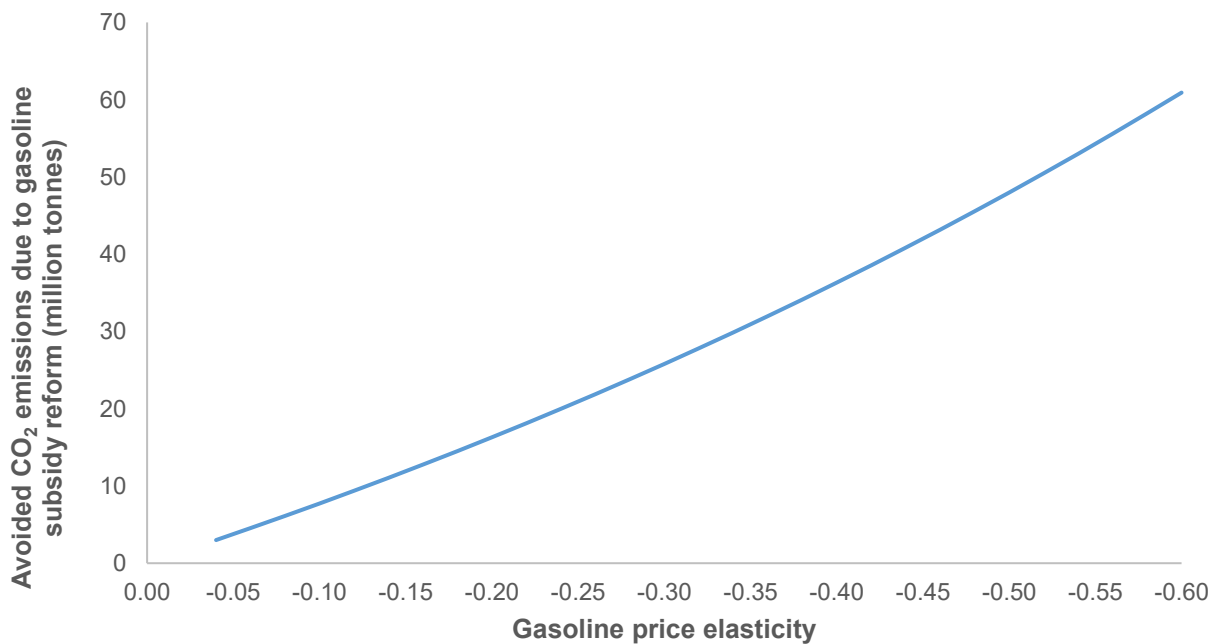
### 3.7.3 Sensitivity analysis: welfare and emission impacts

The impacts of energy subsidy reform on welfare and emissions are highly dependent on the size of the price elasticity. Figure 8 and Figure 9 illustrate how the estimated size of the welfare gain and the emission reduction due to the energy subsidy reforms implemented in 2016 and 2018 vary with the price elasticity of energy demand, using gasoline as an example. At my estimated long-run gasoline price elasticity of -0.16, the welfare gain due to the implemented gasoline subsidy reforms is around 6 billion 2010 USD. Using the assumed price elasticity of -0.5 used by Coady et al. (2015, 2017), this welfare gain rises to almost 23 billion 2010 USD. Using the even larger gasoline price elasticity assumed by Davis (2017), the welfare gain rises further to around 29 billion 2010 USD. The implications on avoided CO<sub>2</sub> emissions are arguably even larger. At my estimated long-run gasoline price elasticity of -0.16, the avoided CO<sub>2</sub> emissions due to the implemented gasoline subsidy reforms are around 13 Mt. Using the assumed price elasticity of -0.5 used by Coady et al. (2015, 2017), this CO<sub>2</sub> emission reduction rises to

48 Mt. Using the even larger gasoline price elasticity assumed by Davis (2017), the emission reduction rises further to over 60 Mt. This massive variation in the results of the impact analysis reinforces the need to accurately estimate unbiased price elasticities, as discussed in Chapter 2, instead of assuming a certain value for them.



**Figure 8** Welfare gain in 2018 due to implemented gasoline subsidy reform versus size of gasoline price elasticity.



**Figure 9** Avoided emissions in 2018 due to implemented gasoline subsidy reform versus size of gasoline price elasticity.

### 3.7.4 Fiscal impact analysis results

Using my estimated price elasticities from Chapter 2, I quantify the actual fiscal impacts of the implemented partial energy subsidy reforms in Saudi Arabia and the potential fiscal impacts of further reforms (all the way up to the reference prices) if they were to be implemented. My analysis is done using both short- and long-run price elasticities.

Using the price-gap equation and the variations of it that were introduced in Section 3.5.3.1 and 3.5.3.2 of this chapter, and assuming that all the domestically saved fuel is exported (i.e.,  $\mu_t^{j,k} = 1$ ), I estimate the fiscal impacts of the implemented partial energy subsidy reforms in Saudi Arabia. I find that these partial reforms generated a long-run fiscal revenue uplift of 10.5 billion 2010 USD in 2016, rising to 11.2 billion 2010 USD in 2017 and up to 22.1 billion 2010 USD in 2018 after the second wave of partial reform took place. These results are shown in Table 18. According to SAMA (2020), total government revenues in Saudi Arabia in 2018 were 241.5 billion USD, or 203.7 billion 2010 USD when adjusted for inflation. Therefore, the implemented energy subsidy reforms contributed more than 10% of total government revenues in 2018, highlighting energy subsidy reform's important role in promoting fiscal sustainability. Moreover, further energy subsidy reforms, if implemented in 2018, could have resulted in an additional fiscal gain of 30.3 billion 2010 USD in that year, raising total government revenue by 15 percent.

Table 19 shows the fiscal impacts using the short-run price elasticities. My short-run analysis reveals that the fiscal impacts from the partial energy subsidy reforms implemented in Saudi Arabia were slightly smaller than those estimated using the long-run price elasticities. This gap stems from the strength of the consumer response to higher fuel prices. For traded fuels like gasoline and diesel, a stronger response by domestic consumers following partial energy subsidy reform, where the partially reformed domestic price remains below the international market price, leads to greater fuel savings and thus a larger fiscal gain that can be achieved by exporting the saved fuel at the higher international market price. In the case of full energy subsidy reform, where the fully reformed domestic price is equal to the reference price, the consumer response no longer affects the fiscal gain as fuel is sold domestically and exported internationally at the same price, which is the international market price for traded fuels. Therefore, the potential fiscal impacts of further subsidy reforms, measured using short- or long-run elasticities, are equivalent.

On a final note, the revenue from selling fuel and electricity at higher energy prices following energy subsidy reform is not necessarily 100% government revenue. For example, since the Saudi government's initial public offering for shares of Saudi Aramco, Saudi Arabia's national oil company, the government's ownership share has declined to 97.62% of issued shares (Saudi Aramco, 2024). The Saudi government is also the major shareholder for the Saudi Electricity Company, the country's primary electricity provider, and that share is around 80% (Aldubyan and Gasim, 2021). Therefore, most but not all the estimated revenue gains calculated using the price-gap equation and its many variations reflect government revenue gains.

**Table 18** *The fiscal impacts (in billion 2010 USD) from actual and potential energy subsidy reforms using the long-run price elasticities.*

| <b>End-use sector:</b><br><i>Energy product</i> | <b>Actual fiscal impacts of the implemented energy subsidy reforms</b><br><i>(moving from pre-reform prices to baseline reformed prices in each year)</i> |             |             | <b>Potential fiscal impacts of further subsidy reforms</b><br><i>(moving from baseline reformed prices to fully reformed prices in each year)</i> |             |             |
|-------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|-------------|---------------------------------------------------------------------------------------------------------------------------------------------------|-------------|-------------|
|                                                 | <b>2016</b>                                                                                                                                               | <b>2017</b> | <b>2018</b> | <b>2016</b>                                                                                                                                       | <b>2017</b> | <b>2018</b> |
| <b>Transport:</b>                               |                                                                                                                                                           |             |             |                                                                                                                                                   |             |             |
| Gasoline                                        | 2.6                                                                                                                                                       | 2.8         | 8.4         | 4.4                                                                                                                                               | 6.3         | 3.7         |
| Diesel                                          | 2.4                                                                                                                                                       | 2.5         | 2.9         | 5.2                                                                                                                                               | 6.5         | 8.9         |
| Kerosene                                        | 0.1                                                                                                                                                       | 0.1         | 0.1         | 0.2                                                                                                                                               | 0.2         | 0.3         |
| <b>Residential:</b>                             |                                                                                                                                                           |             |             |                                                                                                                                                   |             |             |
| LPG                                             | 0.0                                                                                                                                                       | 0.0         | 0.0         | -0.1                                                                                                                                              | 0.0         | 0.1         |
| Electricity                                     | 0.5                                                                                                                                                       | 0.3         | 4.2         | 6.6                                                                                                                                               | 6.8         | 3.3         |
| <b>Commercial &amp; governmental:</b>           |                                                                                                                                                           |             |             |                                                                                                                                                   |             |             |
| Electricity                                     | 1.4                                                                                                                                                       | 1.4         | 1.9         | 0.9                                                                                                                                               | 0.9         | 0.6         |
| <b>Industrial:</b>                              |                                                                                                                                                           |             |             |                                                                                                                                                   |             |             |
| Natural gas                                     | 1.3                                                                                                                                                       | 1.1         | 1.2         | 2.1                                                                                                                                               | 1.7         | 2.0         |
| Crude oil                                       | 0.1                                                                                                                                                       | 0.0         | 0.0         | 0.4                                                                                                                                               | 0.2         | 0.3         |
| Diesel                                          | 0.2                                                                                                                                                       | 0.2         | 0.2         | 0.9                                                                                                                                               | 1.0         | 1.0         |
| Heavy fuel oil                                  | 0.6                                                                                                                                                       | 1.2         | 1.5         | 2.5                                                                                                                                               | 5.2         | 6.9         |
| Electricity                                     | 0.5                                                                                                                                                       | 0.6         | 0.6         | 1.0                                                                                                                                               | 1.1         | 1.2         |
| <b>Non-energy (feedstock):</b>                  |                                                                                                                                                           |             |             |                                                                                                                                                   |             |             |
| Natural gas                                     | 0.1                                                                                                                                                       | 0.1         | 0.1         | 0.5                                                                                                                                               | 0.5         | 0.5         |
| Ethane                                          | 0.7                                                                                                                                                       | 0.8         | 0.8         | 1.4                                                                                                                                               | 1.4         | 1.5         |
| LPG                                             | 0.0                                                                                                                                                       | 0.1         | 0.0         | 0.0                                                                                                                                               | 0.0         | 0.0         |
| Naphtha                                         | 0.1                                                                                                                                                       | 0.1         | 0.1         | -0.1                                                                                                                                              | 0.0         | -0.1        |
| <b>Total</b>                                    | <b>10.5</b>                                                                                                                                               | <b>11.2</b> | <b>22.1</b> | <b>25.8</b>                                                                                                                                       | <b>31.9</b> | <b>30.3</b> |

**Table 19** The fiscal impacts (in billion 2010 USD) from actual and potential energy subsidy reforms using the short-run price elasticities.

| <b>End-use sector:<br/>Energy product</b> | <b>Actual fiscal impacts of the implemented<br/>energy subsidy reforms</b><br>(moving from pre-reform prices to baseline<br>reformed prices in each year) |             |             | <b>Potential fiscal impacts of further subsidy<br/>reforms</b><br>(moving from baseline reformed prices to fully<br>reformed prices in each year) |             |             |
|-------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|-------------|---------------------------------------------------------------------------------------------------------------------------------------------------|-------------|-------------|
|                                           | <b>2016</b>                                                                                                                                               | <b>2017</b> | <b>2018</b> | <b>2016</b>                                                                                                                                       | <b>2017</b> | <b>2018</b> |
| <b>Transport:</b>                         |                                                                                                                                                           |             |             |                                                                                                                                                   |             |             |
| Gasoline                                  | 2.5                                                                                                                                                       | 2.6         | 7.9         | 4.4                                                                                                                                               | 6.3         | 3.7         |
| Diesel                                    | 2.3                                                                                                                                                       | 2.4         | 2.8         | 5.2                                                                                                                                               | 6.5         | 8.9         |
| Kerosene                                  | 0.1                                                                                                                                                       | 0.1         | 0.1         | 0.2                                                                                                                                               | 0.2         | 0.3         |
| <b>Residential:</b>                       |                                                                                                                                                           |             |             |                                                                                                                                                   |             |             |
| LPG                                       | 0.0                                                                                                                                                       | 0.0         | 0.0         | -0.1                                                                                                                                              | 0.0         | 0.1         |
| Electricity                               | 0.5                                                                                                                                                       | 0.3         | 4.2         | 6.6                                                                                                                                               | 6.8         | 3.3         |
| <b>Commercial &amp; governmental:</b>     |                                                                                                                                                           |             |             |                                                                                                                                                   |             |             |
| Electricity                               | 1.4                                                                                                                                                       | 1.4         | 1.9         | 0.9                                                                                                                                               | 0.9         | 0.6         |
| <b>Industrial:</b>                        |                                                                                                                                                           |             |             |                                                                                                                                                   |             |             |
| Natural gas                               | 1.6                                                                                                                                                       | 1.3         | 1.5         | 2.1                                                                                                                                               | 1.7         | 2.0         |
| Crude oil                                 | 0.0                                                                                                                                                       | 0.0         | 0.0         | 0.4                                                                                                                                               | 0.2         | 0.3         |
| Diesel                                    | 0.2                                                                                                                                                       | 0.2         | 0.2         | 0.9                                                                                                                                               | 1.0         | 1.0         |
| Heavy fuel oil                            | 0.4                                                                                                                                                       | 0.6         | 0.8         | 2.5                                                                                                                                               | 5.2         | 6.9         |
| Electricity                               | 0.5                                                                                                                                                       | 0.6         | 0.6         | 1.0                                                                                                                                               | 1.1         | 1.2         |
| <b>Non-energy (feedstock):</b>            |                                                                                                                                                           |             |             |                                                                                                                                                   |             |             |
| Natural gas                               | 0.1                                                                                                                                                       | 0.1         | 0.1         | 0.5                                                                                                                                               | 0.5         | 0.5         |
| Ethane                                    | 0.5                                                                                                                                                       | 0.5         | 0.6         | 1.4                                                                                                                                               | 1.4         | 1.5         |
| LPG                                       | 0.0                                                                                                                                                       | 0.1         | 0.0         | 0.0                                                                                                                                               | 0.0         | 0.0         |
| Naphtha                                   | 0.1                                                                                                                                                       | 0.1         | 0.1         | -0.1                                                                                                                                              | 0.0         | -0.1        |
| <b>Total</b>                              | <b>9.9</b>                                                                                                                                                | <b>10.3</b> | <b>20.6</b> | <b>25.8</b>                                                                                                                                       | <b>31.9</b> | <b>30.3</b> |

### 3.7.5 How additional fuel exports influence the international market price and the fiscal impacts

Using the method presented in Section 3.5.3.3, specifically Equation [30], I demonstrate how the potential fiscal impacts from further energy subsidy reform change when allowing domestic and international markets to respond to Saudi Arabia's reform. I refer to these estimates of the fiscal impacts as the "refined" estimates. My analysis focuses on the six traded fuels in Saudi Arabia: gasoline, diesel, kerosene, fuel oil, LPG, and crude oil. To simplify the presentation of the results, they are shown in current USD for the year 2018 only, in contrast to the previous results, which were shown for the 2016-2018 period and in units of constant 2010 USD. Moreover, my refined estimates for the fiscal impacts combine the consumption of the same fuels across different sectors (e.g., diesel for transport and diesel for industry are combined in the analysis). An assumption is made that all the domestically saved fuel is exported, such that  $\mu_t = 1$ .

When the price elasticity of domestic fuel demand is zero, no additional fuel is freed up for export, so domestic demand and the international market price remain unchanged. As a result, the refined estimate obtained using Equation [30] is the same as the previously presented estimate derived from the price-gap equation. However, as the domestic price elasticity ( $\zeta$ ) increases in absolute terms, removing the subsidy reduces domestic demand, resulting in domestic fuel savings that can be exported. Higher exports then lower the international fuel price, with the responsiveness of the international fuel price to additional Saudi fuel exports becoming stronger as the elasticity of the international fuel price with respect to Saudi exports ( $1/\eta$ ) increases. Table 20 shows the results obtained using the long-run domestic gasoline price elasticity estimated in Chapter 2 ( $\zeta = -0.16$ ) and the long-run elasticity of Saudi exports with respect to the international fuel price that was estimated by Karanfil and Pierru (2021) ( $\eta = -6.12$ , which implies that  $1/\eta = -0.16$ ). The results in Table 20 demonstrate that, at these specific elasticity values, the potential fiscal gain from full gasoline subsidy reform falls from 4.4 billion USD (this is the price-gap estimate, which is equal to 3.7 billion in constant 2010 USD, the value that was presented previously in Table 18) to 4.0 billion USD (the refined estimate) after accounting for the domestic and international market responses.

The results, however, are highly sensitive to the values of the two elasticities. Figure 10 shows the fiscal impact of full gasoline subsidy reform at a range of elasticities. Since the long-run elasticity of  $1/\eta = -0.16$  was estimated by Karanfil and Pierru (2021) for Saudi Arabia using crude oil data, and since Saudi exports of gasoline are relatively smaller than its crude oil exports (GASTAT, 2022), it is possible that the international fuel price elasticity may be smaller for gasoline. Therefore, I present the fiscal impacts for a wider range of international fuel price elasticities. Figure 10 shows that when the domestic and international market responses are zero, the fiscal impact is equal to the price-gap estimate of 4.4 billion USD (3.7 billion constant 2010 USD). However, as the elasticities rise above zero in absolute terms, the fiscal gain from full gasoline subsidy reform decreases because of domestic gasoline savings leading to additional Saudi gasoline exports that then depress the international gasoline price. For small international fuel price elasticities, the additional Saudi fuel exports have minimal impact on the international fuel price. However, as the international fuel price elasticity grows larger in absolute terms, additional Saudi exports have a bigger impact on the international fuel price, reducing the potential fiscal gain. At my estimated domestic gasoline price elasticity of -0.16 (equivalent to an arc elasticity of -0.14) and an international price elasticity of -0.05, the potential fiscal

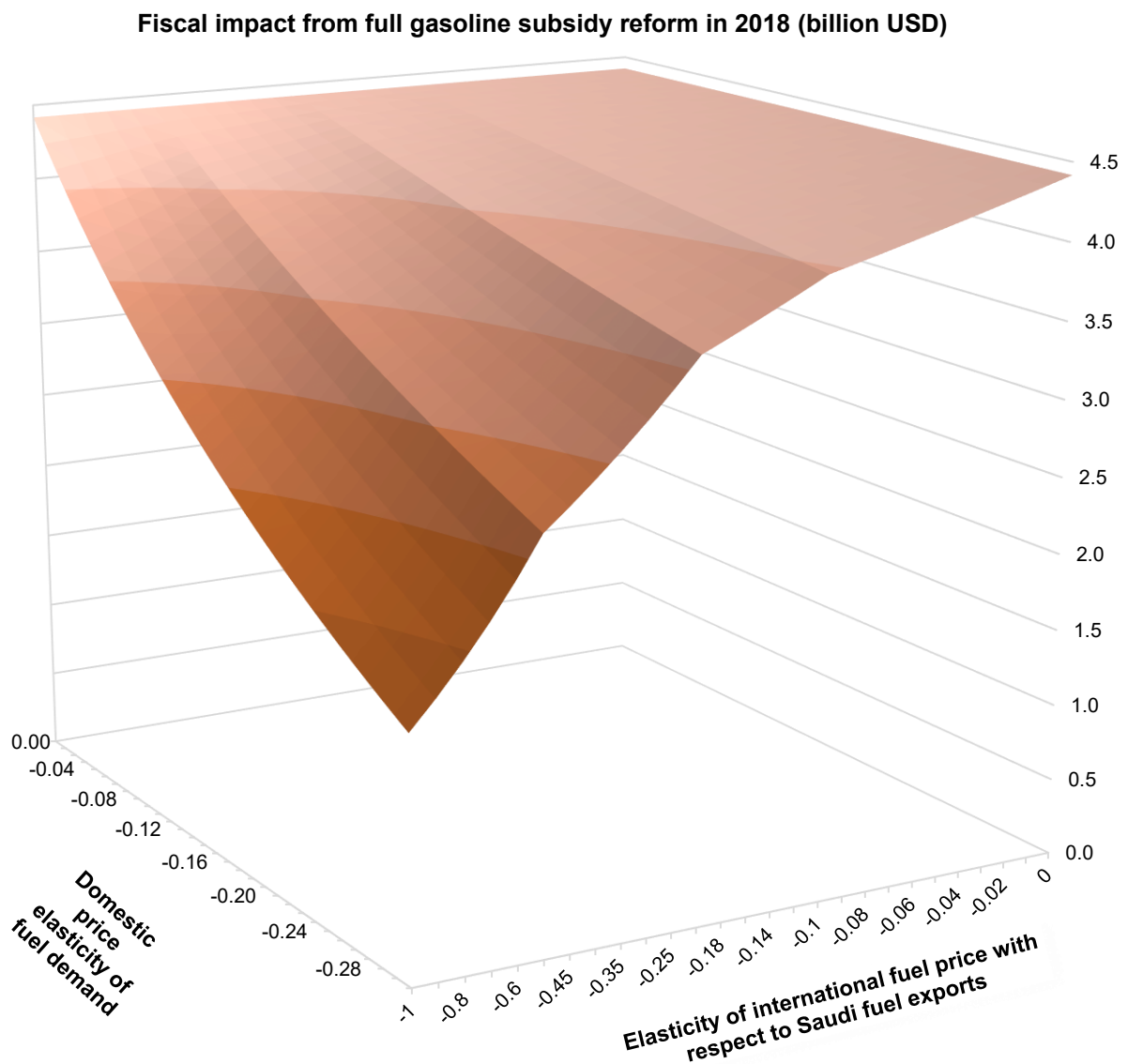
gain from full gasoline subsidy reform in 2018 falls from 4.4 billion USD (the price-gap estimate) to only 4.3 billion USD. At an extreme international price elasticity of -0.50, the potential fiscal gain can fall to as low as 3.5 billion USD.

**Table 20** Fiscal gain from full gasoline subsidy reform in 2018 at specific estimated elasticities.

|                                                                                                                                                           |       |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------|-------|
| <b>Domestic annual gasoline consumption before full gasoline subsidy reform (million barrels)</b>                                                         | 193.6 |
| <b>Domestic annual gasoline consumption after full gasoline subsidy reform (million barrels)</b>                                                          | 182.9 |
| <b>Domestic annual gasoline savings (million barrels)</b>                                                                                                 | 10.7  |
| <b>Annual gasoline exports before full gasoline subsidy reform (million barrels)</b>                                                                      | 120.3 |
| <b>Annual gasoline exports after full gasoline subsidy reform (million barrels)</b>                                                                       | 131.0 |
| <b>International gasoline price before full gasoline subsidy reform (USD per barrel)</b>                                                                  | 85.2  |
| <b>International gasoline price after full gasoline subsidy reform (USD per barrel)</b>                                                                   | 83.9  |
| <b>Fiscal gain from gasoline subsidy reform without accounting for the domestic and international market responses [price-gap estimate] (billion USD)</b> | 4.42  |
| <b>Fiscal gain from gasoline subsidy reform after accounting for the domestic and international market responses [refined estimate] (billion USD)</b>     | 4.01  |

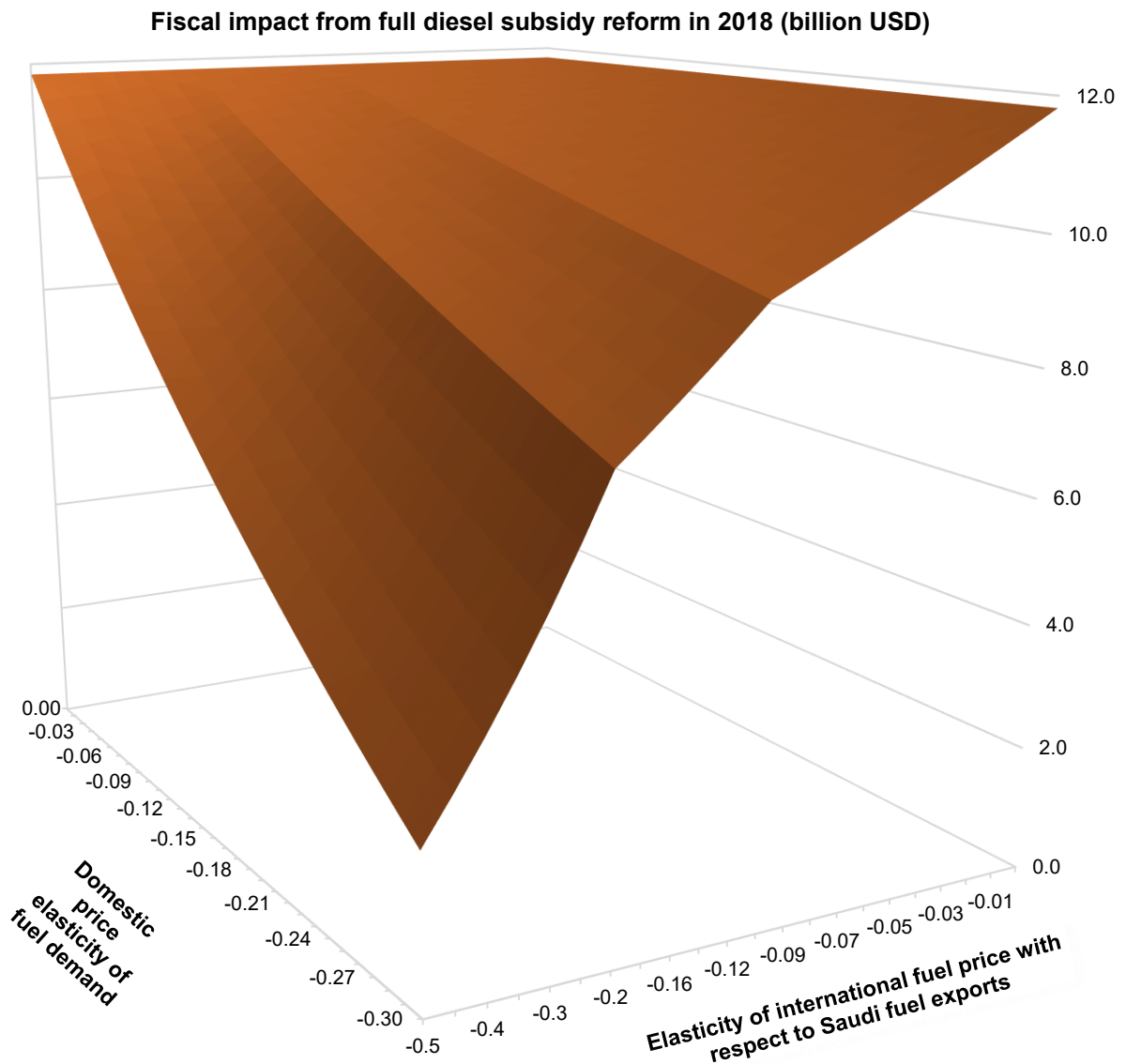
*Notes: The results shown above were obtained with the following elasticities:*

$\zeta = -0.16$  and  $1/\eta = -0.16$ .



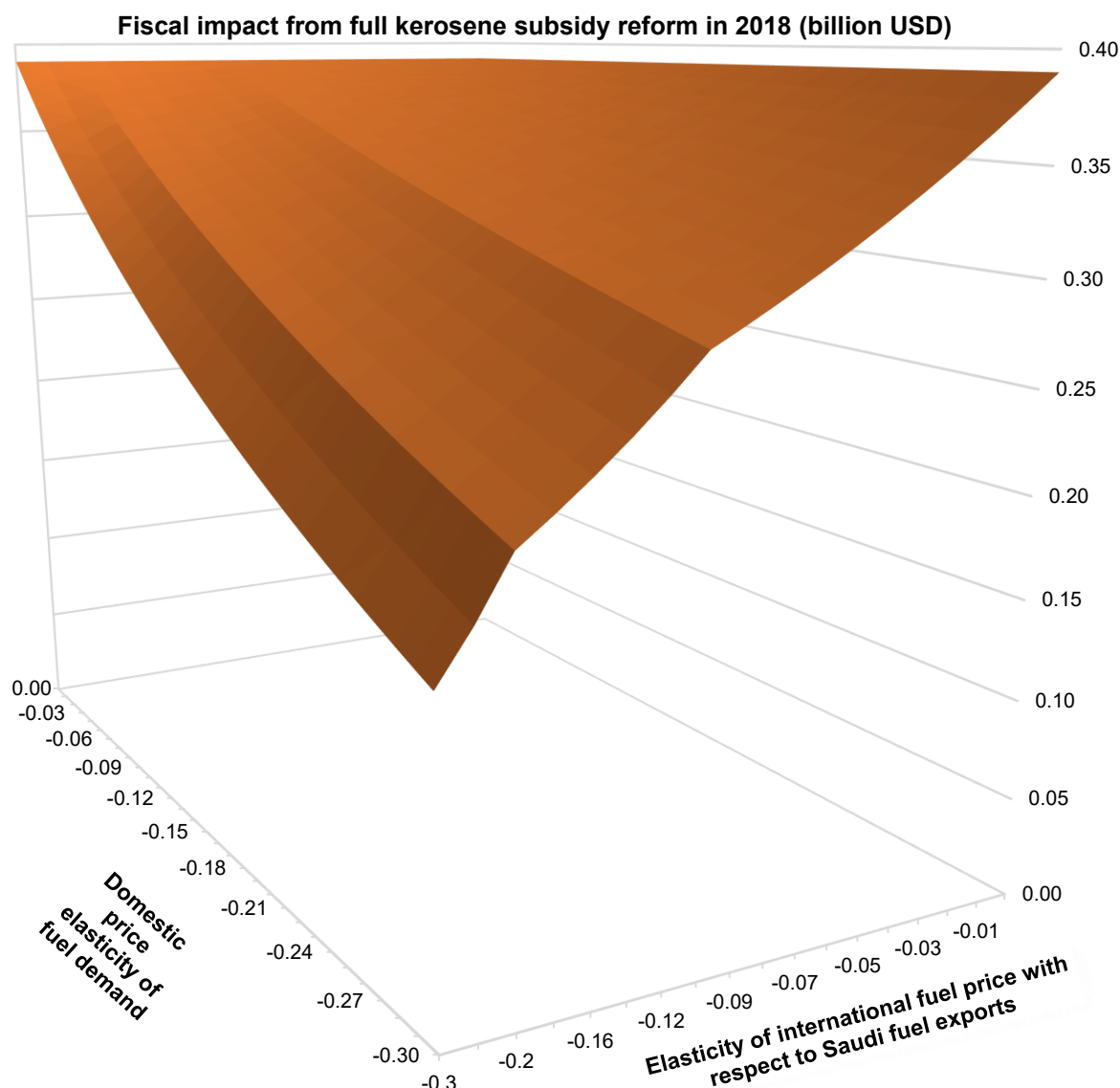
**Figure 10** Fiscal gain from full gasoline subsidy reform in 2018 at a range of elasticities.

Figure 11 shows the fiscal impact of full diesel subsidy reform at a range of elasticities. When the domestic and international market responses are zero, the potential fiscal impact is equal to the price-gap estimate of 11.8 billion USD, which is made up of a 10.5 billion USD fiscal gain due to transport diesel subsidy reform and a 1.2 billion USD fiscal gain due to industrial diesel subsidy reform. (For comparison to Table 18, the values are 8.9 billion and 1.0 billion in constant 2010 USD.) At my estimated domestic diesel price elasticity of -0.29 (equivalent to an arc elasticity of -0.11) and an international price elasticity of -0.05, the potential fiscal gain from full diesel subsidy reform in 2018 falls from 11.8 billion USD (the price-gap estimate) to 11.4 billion USD. At an extreme international price elasticity of -0.5, the potential fiscal gain can fall to as low as 4.4 billion USD.



**Figure 11** Fiscal gain from full diesel subsidy reform in 2018 at a range of elasticities.

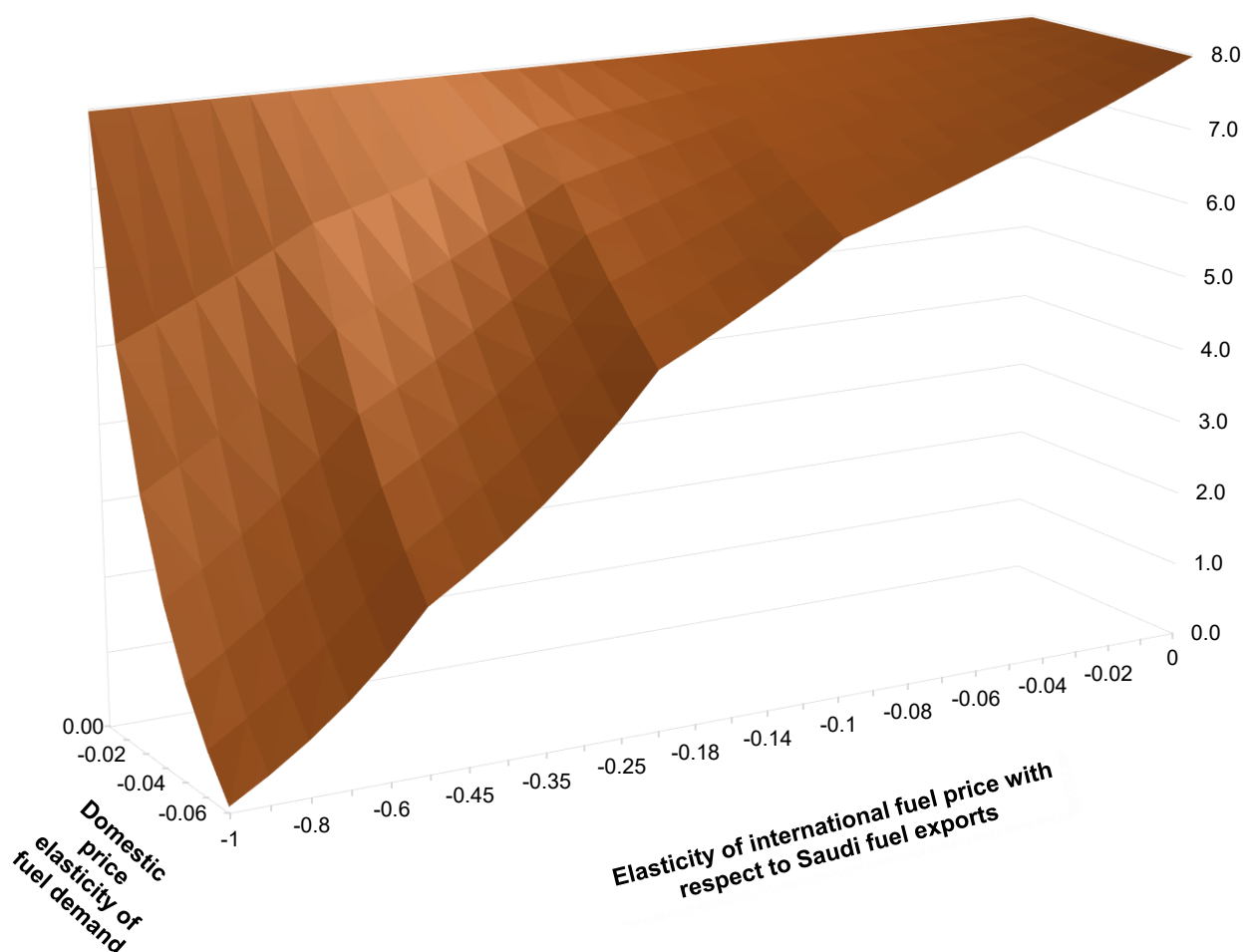
Figure 12 shows the fiscal impact of full kerosene subsidy reform at a range of elasticities. When the domestic and international market responses are zero, the potential fiscal impact is equal to the price-gap estimate of 0.39 billion USD. At my estimated domestic kerosene price elasticity of -0.19 (equivalent to an arc elasticity of -0.12) and an international price elasticity of -0.05, the potential fiscal gain from full kerosene subsidy reform in 2018 falls from 0.39 billion USD (the price-gap estimate) to 0.36 billion USD. At an extreme international price elasticity of -0.3, the potential fiscal gain can fall to as low as 0.27 billion USD.



**Figure 12** Fiscal gain from full kerosene subsidy reform in 2018 at a range of elasticities.

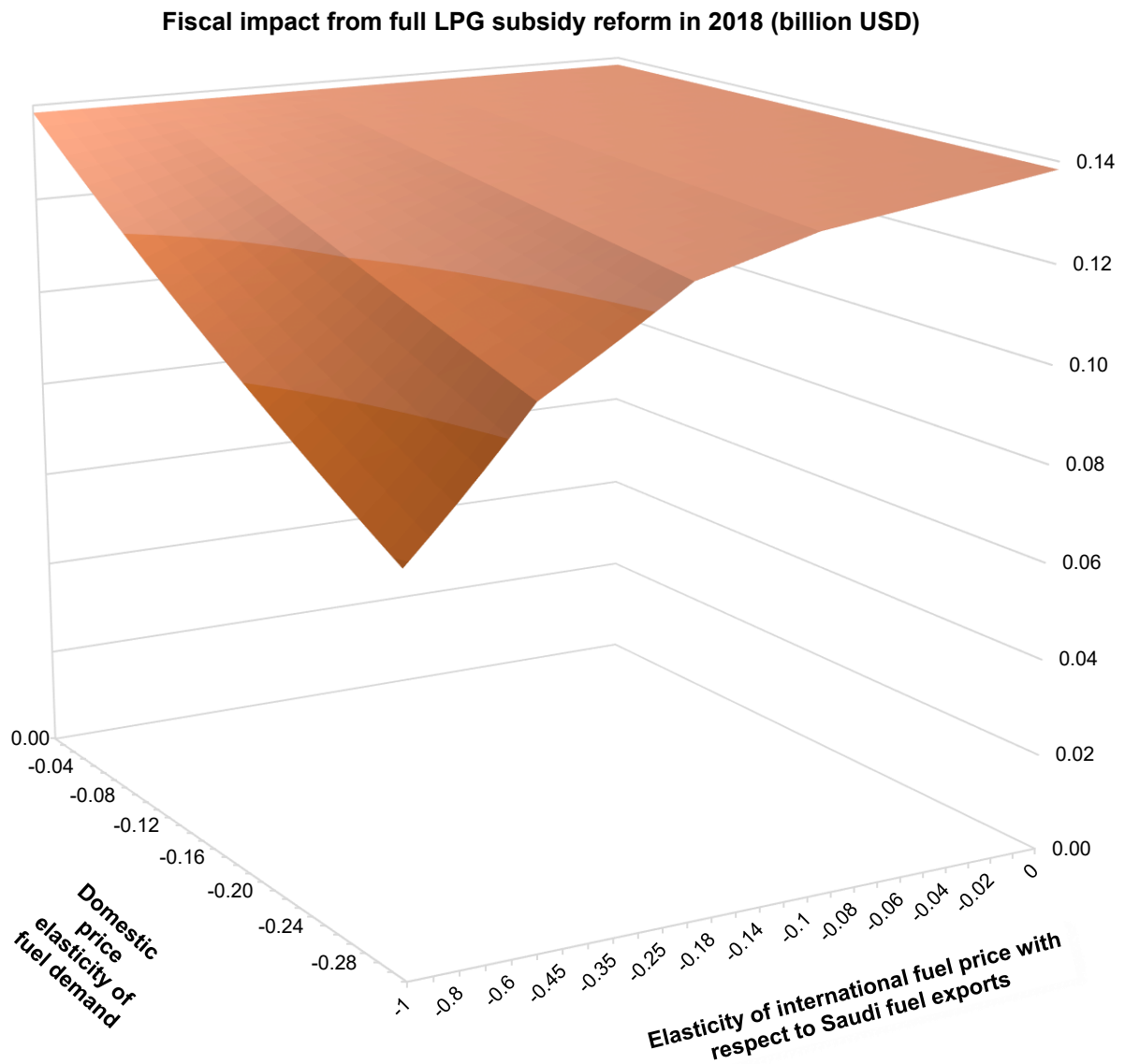
Figure 13 shows the fiscal impact of full heavy fuel oil subsidy reform at a range of elasticities. When the domestic and international market responses are zero, the potential fiscal impact is equal to the price-gap estimate of 8.0 billion USD (or 6.9 billion at constant 2010 USD). At my estimated domestic heavy fuel oil price elasticity of -0.14 (equivalent to an arc elasticity of -0.03) and an international price elasticity of -0.05, the potential fiscal gain from full heavy fuel oil subsidy reform in 2018 falls from 8.0 billion USD (the price-gap estimate) to 7.5 billion USD. At an extreme international price elasticity of -0.5, the potential fiscal gain can fall to as low as 4.2 billion USD.

### Fiscal impact from full heavy fuel oil subsidy reform in 2018 (billion USD)



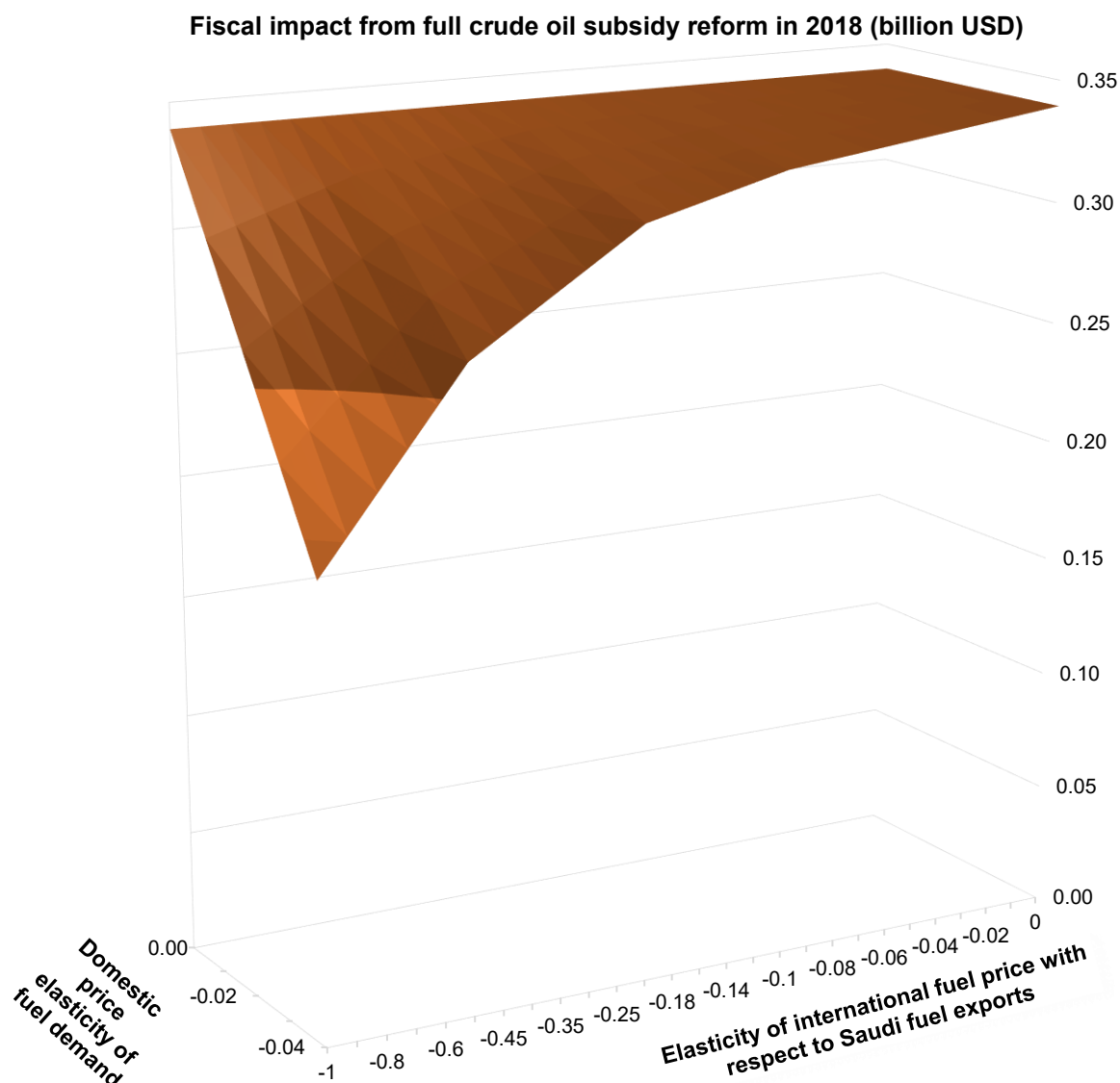
**Figure 13** Fiscal gain from full heavy fuel oil subsidy reform in 2018 at a range of elasticities.

Figure 14 shows the fiscal impact of full LPG subsidy reform at a range of elasticities. Even when the domestic and international market responses are zero, the potential fiscal impact is very small, equal to only 0.14 billion USD (the price-gap estimate). At my estimated domestic industrial LPG price elasticity of -0.31 (equivalent to an arc elasticity of -0.29) and an assumed international price elasticity of -0.05, there is an insignificant decrease in the size of the fiscal impact. Even at an extreme international price elasticity of -1, the potential fiscal gain falls from 0.14 to only 0.08 billion USD.



**Figure 14** Fiscal gain from full LPG subsidy reform in 2018 at a range of elasticities.

Figure 15 shows the fiscal impact of full crude oil subsidy reform at a range of elasticities. When the domestic and international market responses are zero, the potential fiscal impact is equal to the price-gap estimate of 0.34 billion USD. At my estimated domestic crude oil price elasticity of -0.14 (equivalent to an arc elasticity of -0.03) and an international price elasticity of -0.16 (estimated by Karanfil and Pierru (2021) for crude oil specifically), the potential fiscal gain from full crude oil subsidy reform in 2018 falls from 0.34 (the price-gap estimate) to only 0.32 billion USD. At an extreme international price elasticity of -1, the potential fiscal gain can fall to as low as 0.28 billion USD.



**Figure 15** Fiscal gain from full crude oil subsidy reform in 2018 at a range of elasticities.

Table 21 summarizes the results by comparing the price-gap estimates of the fiscal impacts to the refined estimates, using the price elasticities estimated in Chapter 2 (converted into arc elasticities, as discussed in Appendix B<sup>14</sup>). The refined estimates in Table 21 are presented for two sets of international fuel price elasticities: the long-run value of  $\eta = -0.16$  that was estimated by Karanfil and Pierru (2021) specifically for crude oil and a more conservative value of  $\eta = -0.05$ . The analysis demonstrates that the price-

<sup>14</sup> As discussed in Appendix B, point and arc elasticities diverge for large percentage increases. In the case of the domestic fuel price elasticity, fuel subsidy reform leads to large percentage increases in domestic prices, which cause the point and arc elasticities to diverge. However, in the case of the international fuel price elasticity, fuel subsidy reform generally leads to small percentage increases in Saudi fuel exports, allowing the price and arc elasticities to converge.

gap method does indeed over-estimate the fiscal impacts of energy subsidy reform in Saudi Arabia. Although the method introduced in Section 3.5.3.3, which accounts for the domestic and international market responses to subsidy reform, produces a smaller total fiscal gain, the decrease is not very large when compared to the price-gap estimate, especially when using a more conservative international fuel price elasticity.

**Table 21** The fiscal impacts (in billion current USD) using the price-gap and refined method.

| Energy product<br>(end-use sectors)                       | Potential fiscal impacts of further subsidy reform<br>(moving from baseline reformed prices to fully reformed prices) |                                                                                       |                                                                          |
|-----------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|--------------------------------------------------------------------------|
|                                                           | Price-gap estimate                                                                                                    | Refined estimate<br>(at conservative international<br>fuel price elasticity of -0.05) | Refined estimate<br>(at international fuel price<br>elasticity of -0.16) |
| Gasoline<br>(transport)                                   | 4.4                                                                                                                   | 4.3                                                                                   | 4.1                                                                      |
| Diesel (transport<br>and industry)                        | 11.8                                                                                                                  | 11.4                                                                                  | 10.4                                                                     |
| Kerosene<br>(transport)                                   | 0.39                                                                                                                  | 0.36                                                                                  | 0.32                                                                     |
| LPG (residential<br>and transport)                        | 0.14                                                                                                                  | 0.14                                                                                  | 0.13                                                                     |
| Heavy fuel oil<br>(industry)                              | 8.0                                                                                                                   | 7.5                                                                                   | 6.4                                                                      |
| Crude oil (industry)                                      | 0.34                                                                                                                  | 0.33                                                                                  | 0.32                                                                     |
| <b>Total fiscal gain</b>                                  | <b>25.1</b>                                                                                                           | <b>24.0</b>                                                                           | <b>21.7</b>                                                              |
| <b>% decrease<br/>relative to price-<br/>gap estimate</b> | <b>0%</b>                                                                                                             | <b>-4.1%</b>                                                                          | <b>-13.6%</b>                                                            |

### 3.8 Conclusion

Using the estimated price elasticities from Chapter 2, I was able to conduct a comprehensive analysis of the economic, environmental, and fiscal impacts of energy subsidy reform in Saudi Arabia. Although the general inelasticity of energy demand in Saudi Arabia may suggest that energy price increases do not affect demand significantly, thereby yielding only small benefits, I find the opposite to be true, mainly due to the extent of the domestic price increases that occurred and the scope for further energy price increases. For example, the 95-octane gasoline price increased by around 240% between 2015 and 2018. Even with a small price elasticity of -0.1, such a price change delivers a

24% reduction in gasoline consumption, all else equal, thereby yielding considerable economic, environmental, and fiscal benefits.

I find significant welfare gains from the two waves of partial energy subsidy reform implemented by the Saudi government in 2016 and 2018. My long-run analysis reveals that in 2018 the reforms produced a total annual welfare gain of 21.9 billion 2010 USD, which is made up of a 6.4 billion 2010 USD reduction in deadweight loss and a 15.4 billion 2010 USD reduction in external costs. These external costs, which are associated with fuel and electricity consumption, include CO<sub>2</sub> emissions, local air pollution, and, in the case of transport fuels, congestion, accidents, and road damages. The total welfare gain in 2018 represents around 3% of real Saudi GDP in that year, highlighting the significant economic gains that have been achieved in Saudi Arabia through energy subsidy reform.

The climate change mitigation co-benefits of energy subsidy reform in Saudi Arabia are also important. My analysis reveals that the 2016 wave of partial reform delivered 51.3 Mt of avoided CO<sub>2</sub> emissions annually, a value that rose to 66.5 Mt by 2018 as the second reform ensued. The annual avoided emissions in 2018 represent around 11% of actual energy-related CO<sub>2</sub> emissions in Saudi Arabia in that year (BP, 2020), and over 50% of Saudi Arabia's first NDC target. Although fiscal and resource concerns were the primary drivers of these past energy subsidy reforms, the Saudi government was able to achieve extensive climate change mitigation co-benefits.

There remains scope for further energy subsidy reform until domestic energy prices are 100% linked with their reference prices. I find that further energy subsidy reforms, had they been implemented in 2018, could have produced an additional welfare gain of 30.7 billion 2010 USD. Moreover, further reform in 2018 could have delivered almost 95 Mt of avoided CO<sub>2</sub> emissions annually. These avoided emissions represent over one-third of Saudi Arabia's updated NDC target for avoided annual GHG emissions by 2030 (Kingdom of Saudi Arabia, 2021). These results demonstrate that further energy subsidy reforms can contribute significantly to Saudi Arabia's more ambitious updated NDC target, but also that other policy instruments, like carbon pricing, may be needed to fully achieve that target and any further targets from future NDC updates, which should be more ambitious.

The fiscal gains from energy subsidy reform have traditionally been the primary drivers of implementation, and my analysis confirms the significance of these fiscal gains using variations of the price-gap method. I find that the partial reforms implemented by the Saudi government in 2016 and 2018 generated a fiscal revenue uplift of 10.5 billion 2010 USD in

2016, 11.2 billion 2010 USD in 2017, and 22.1 billion 2010 USD in 2018. These partial reforms contributed more than 10% of total government revenues in 2018, while further energy subsidy reforms, if implemented in 2018, could have resulted in an additional revenue uplift of 30.3 billion 2010 USD in that year, raising total government revenue by 15 percent.

However, there have been academic and policy discussions on the fiscal impacts potentially being lower due to the fuel savings that result from energy subsidy reform and the impacts of additional fuel exports from countries like Saudi Arabia on the international fuel price. Using a newly proposed method, I demonstrate that the price-gap method does indeed over-estimate the fiscal impacts of energy subsidy reform in Saudi Arabia, but not by much. The fiscal gains remain large even when accounting for the effect of additional fuel exports on international fuel prices.

In summary, this chapter demonstrated that energy subsidy reforms could deliver significant welfare gains for the Saudi economy, contribute considerably to achieving Saudi Arabia's updated NDC target, and support fiscal sustainability. However, further energy subsidy reforms will be challenging to implement. Increases in energy prices are generally more feasible when prices are relatively low, which was the case with the 2016 and 2018 reforms in Saudi Arabia. However, energy prices are currently significantly higher than they were just a few years ago. To successfully implement further energy subsidy reforms and unlock the economic, environmental, and fiscal gains presented in this chapter, policymakers in Saudi Arabia will need to learn from their own past attempts, which have been successful, and from the many attempts at energy subsidy reform from energy-subsidizing countries around the world.

# Chapter 4: Lessons for Successful Energy Subsidy Reforms

## 4.1 Introduction

This chapter seeks to build a better understanding of how policymakers in Saudi Arabia can overcome the barriers and implement further energy subsidy reforms successfully. Chapter 3 demonstrated that further energy subsidy reforms can unlock considerable economic, environmental, and fiscal benefits for Saudi Arabia. However, implementing further energy subsidy reforms appears to be challenging. For example, in July 2021, against a backdrop of COVID-19 and rising international oil prices, the Saudi government capped domestic gasoline prices (Arab News, 2021), which have remained fixed at their nominal levels since. Such actions are indicative of the challenges and complexity associated with implementing further energy subsidy reforms. To better navigate these challenges, policymakers in Saudi Arabia can benefit from understanding how different countries were able to reform their energy subsidies successfully, and when countries failed at doing so, given different backdrops of national and global circumstances.

This chapter contributes to building a better understanding of how to implement successful energy subsidy reforms by comprehensively reviewing countries' past experiences with reform over the last few decades. Although a handful of reviews were published on countries' experiences with energy subsidy reform (e.g., Vagliasindi, 2013; Clements et al., 2013; Kojima, 2016), mainly by intergovernmental organizations (IGOs) like the IMF and the World Bank, these reviews primarily focused on selected countries, usually those working closely with the IGOs. Most of these reviews were also published over a decade ago and do not capture some of the more recent reform experiences.

Since most studies in the literature focused on a relatively small subset of countries over a relatively short period, this chapter provides a more comprehensive review of a much larger number of energy subsidy reforms with an expanded geographical and temporal scope, leading to a deeper understanding of the factors that have enabled successful outcomes. This is delivered by 1) first distilling the lessons from past reform attempts from previous reviews published in the literature and then 2) deriving further insights by analyzing a newly constructed database of reforms and looking for evidence that may support, contradict, or add nuance to the lessons I synthesized from the literature. My original database of news articles covers over 400 episodes of energy subsidy reform

implemented worldwide between 1995 and 2022 across 44 countries. In building this database, I present an alternative approach to learning from countries' experiences with reform that relies on news content, in contrast with studies that relied on the direct experiences of IGOs with fewer countries (e.g., Clements et al. 2013). My analysis focuses on energy subsidy reforms that target energy products used by households, including gasoline, diesel, LPG, kerosene, and residential electricity.<sup>15</sup>

This chapter is structured as follows. Section 4.2 synthesizes common lessons from the literature on how to reform energy subsidies successfully. Section 4.3 discusses how I constructed an original database of news articles with comprehensive coverage of energy subsidy reforms and outcomes, from which I draw further insights. Section 4.4 provides the results of my analysis, where I expound on the lessons from the literature using evidence from the episodes in my database while extracting further insights for policymakers. Finally, Section 4.5 concludes and discusses the policy implications.

## **4.2 Lessons from the Literature**

The factors influencing energy subsidy reform outcomes can be presented as barriers, such as the lack of compensation, or enablers, such as the use of compensation. In this chapter, all lessons are framed as enablers to facilitate discussion. When assessing energy subsidy reform outcomes, I adopt a two-pronged definition of success, in line with the literature, in which a reform is deemed successful if it does not lead to protests and if it is not reversed (Chelminski, 2018; Clements et al., 2013; Hill, 2013; McCulloch et al., 2022).

Recurrent lessons emerge from my assessment of the literature on achieving successful reform outcomes. First, decision-makers need to prepare a comprehensive reform strategy, taking into account various elements. Multiple studies underscored the need for comprehensiveness (Clements et al., 2013, 2014; Rentschler and Bazilian, 2017a,b). Clements et al. (2013, 2014) highlighted three key ingredients for a complete strategy: clear objectives, impact assessments, and stakeholder consultation. Rentschler and Bazilian (2017a,b) defined an integrated strategy as one that encompasses an assessment of subsidies, communication, compensation, revenue redistribution and

---

<sup>15</sup> The analysis initially included natural gas use by households. However, during the search of news databases, very few instances of energy subsidy reform that targeted household natural gas were found, so it was dropped from the analysis.

reinvestment, complementary measures, timing, and price smoothing. Other studies, like Laan et al. (2010), stressed the importance of conducting thorough assessments of existing subsidies and the impacts of their reform. Such assessments were described as a vital part of preparation. The importance of preparing well in advance of reform implementation was highlighted by Laan et al. (2010) and Beaton et al. (2013). With regards to preparation, Victor (2009) stressed the need to first understand the historical drivers of subsidies, stating that any reform strategy needs to “begin with the political logic that led governments to create the subsidy”. In summary, there was agreement in the literature on the need to be prepared and to have a comprehensive strategy, but slight differences around which elements were most important for building such a strategy.

The second lesson states that the timing of energy subsidy reform needs to be appropriate, considering a wide range of factors. These factors include 1) the performance of the economy, as economic downturns can trigger social unrest (Kollias and Tzeremes 2022); 2) global macroeconomic conditions, as public support for reform appears to be stronger when those conditions are favourable (Atansah et al., 2017); 3) economic and political stability, as it appears best to reform energy prices “before a political or economic crisis point is reached” (El-Katiri and Fattouh, 2017); 4) changes in the prices of other essential goods, as energy price increases that coincide with other essential price increases could strengthen resistance to reform (Clements et al. 2013, 2014); and 5) government popularity and public trust, as launching reforms early in a government’s term, when new governments tend to be popular, might help deliver a successful outcome (Jazuli et al., 2021; Overland et al., 2016). More generally, Rentschler and Bazilian (2017a,b) listed “smart timing” as a critical element of an integrated strategy. While these appear to be the only factors discussed in the literature, there are likely many more factors that should be considered when timing a reform.

The third lesson states that governments should implement an effective consultation and communication strategy. Many studies have listed communication as a key ingredient for successful energy subsidy reform (UNEP 2003, 2008; Bacon and Kojima, 2006; IMF, 2011b; Vagliasindi, 2013; Beaton et al., 2013; Clements et al., 2013, 2014; Kojima, 2016; Overland et al., 2016; Rentschler and Bazilian, 2017a,b; Atansah et al., 2017), with each study highlighting different elements within the theme of effective communication. These elements include: 1) underscoring all government communications with the costs of subsidies and the benefits of reform (Clements et al., 2013, 2014; UNEP 2003, 2008); 2) ensuring internal coordination within the government before implementation (Beaton et al.

2013; Overland et al., 2016; Whitley and van der Burg, 2018); 3) mapping and identifying key stakeholders and engaging with them to foster public support (Atansah et al., 2017; Bazilian 2017; Beaton et al., 2013); 4) ensuring that communication occurs before, during, and after reform (Whitley and van der Burg 2018); and 5) communicating formally, as “the more formal the way in which the decision to reform subsidies is communicated, the less likely is policy reversal.” (Kojima 2016). In summary, the literature indicates that the more comprehensive the communication approach by the government, the more likely the success of a reform.

The fourth lesson states that governments should implement energy subsidy reforms gradually, ensuring that affected consumers have sufficient time to adapt (UNEP, 2003, 2008; Beaton et al., 2013; Clements et al., 2013, 2014; Overland et al., 2016; Rentschler and Bazilian, 2017a,b; Atansah et al., 2017). Beaton et al. (2013) contrasted a gradual pace of reform with a “big bang” approach, recommending the gradual approach whenever possible but acknowledging that occasionally governments may be forced into a more drastic pace of reform. Overland et al. (2016) proposed a two-year period in their recommendation to the Myanmar government to reform its energy prices. To summarize, there was clear agreement in the literature that gradual implementation is vital.

The fifth lesson revolves around launching compensation schemes and other complementary policies to alleviate the negative impacts of reform on consumers and improve public acceptance (Atansah et al., 2017; Bacon and Kojima, 2006; Beaton et al., 2013; Clements et al., 2013, 2014; Commander, 2012; Laan et al., 2010; Rentschler and Bazilian, 2017a,b; UNEP 2003, 2008; Vagliasindi, 2013; and Whitley and van der Burg, 2018). There is broad agreement on the need to introduce compensation to overcome resistance to reform, but its implementation depends on the availability of institutions for distributing welfare payments to the needy (UNEP, 2003, 2008). Rentschler and Bazilian (2017a,b) discussed how energy subsidy reforms can either utilize existing institutions or in their absence provide an opportunity to establish new social protection infrastructure. With regards to the type of compensation, Clements et al. (2013, 2014) and Vagliasindi (2013) proposed that lifeline rates and cash transfers may perform better. Looking beyond direct compensation, it has been suggested that energy subsidy reforms may be more likely to succeed when implemented alongside a broader set of policies, including complementary policies like energy efficiency regulations that can alleviate the impact of higher energy prices on households (Commander 2012; Laan et al., 2010; Vagliasindi, 2013). Governments can also reinvest part of the reform revenues in other public

initiatives, as discussed by Rentschler and Bazilian (2017a,b) and Whitley and van der Burg (2018).

The sixth and final lesson states that governments should move away from regulated energy pricing to a less politicized automatic or market-based pricing mechanism while minimizing volatility. In doing so, three requirements were highlighted by most studies: 1) the need to depoliticize energy pricing (Clements et al., 2013, 2014) and to establish institutions that *are* independent and are *perceived* as independent to oversee it (Overland et al., 2016); 2) the need to minimize the volatility that arises from linking domestic energy prices to volatile international market prices (Clements et al., 2013, 2014; Rentschler and Bazilian, 2017a,b); and 3) the need to move to either an automatic pricing formula or a market-based pricing mechanism. Some studies proposed either automatic or market-based pricing as valid end points for energy subsidy reform (Clements et al., 2013, 2014), while other studies described automatic formulas as an intermediary step towards market-based pricing (Beaton et al., 2013; Overland et al., 2016). In contrast to a few of these studies, Kojima (2016) pushed back against the need to smoothen volatility, suggesting that doing so could lead to the re-emergence of subsidies.

## 4.3 Methodology

### 4.3.1 Definitions and scope

To look for further insights from as many countries as possible on how to implement energy subsidy reforms successfully, I constructed a database from news articles that reported on energy subsidy reforms and outcomes in countries around the world. My database fills a gap in the literature by providing comprehensive information on reforms and their outcomes, even though there have been a few noticeable attempts. Clements et al. (2013) built one such dataset but it includes only 28 distinct episodes of reform, using only information obtained by IMF staff, probably through direct engagement with governments. Overland et al. (2016) constructed a dataset with 290 reform episodes but simultaneous reforms of different fuels were counted as distinct episodes<sup>16</sup>, and their data

---

<sup>16</sup> Unlike the IMF (Clements et al., 2013), where each energy subsidy reform is defined to include multiple products that were reformed simultaneously, Overland et al. (2016) considered the reform of each product (e.g., gasoline, diesel, LPG, or kerosene) as a distinct episode. So, if four fuels were reformed simultaneously, the IMF would count it as a single episode while Overland et al. (2016) would count it as four distinct episodes. In my database, I follow the same approach as the IMF in defining a single energy subsidy reform episode to include increases in the prices of multiple energy products.

is not publicly available. To the best of my knowledge, there appear to be no other datasets on energy subsidy reforms and outcomes.

This thesis defines an energy subsidy reform as an increase in a country's regulated energy prices that brings them closer to the level they would have been at if they were deregulated. It then defines success to occur when an energy subsidy reform does not lead to protests and is not reversed. The first outcome is important because protests can entail high private and social costs on economies "due to the destruction of assets and infrastructure, disruption to markets, increases in the risk of investment and the loss of trust between social groups and between citizens and state institutions" (McCulloch et al., 2022). The occurrence of protests following reform is thus an unwelcome outcome for policymakers. The occurrence of a policy reversal is equally important because it can eliminate some or all the benefits associated with reform. Chelminski (2018) proposed a similar two-pronged definition of success: "Success is defined by the ability of the government to raise energy prices without overwhelming public protest, and to achieve economic objectives such as reducing government expenditures on subsidies and/or improving aggregate socio-economic welfare and development."

In my database, I focus only on subsidy reforms that targeted household energy products, including gasoline (used in passenger cars), diesel (used in vehicles but also farming, fishing, and rural power generation), LPG (known as cooking gas and used for cooking and heating), kerosene (used for cooking, heating, and lighting), and residential electricity (used to provide a variety of essential energy services). I do not cover reforms targeting only industrial energy products, such as industrial electricity or fuels.

Finally, it is crucial to define how to distinguish separate episodes of energy subsidy reform. In some countries, changes in regulated energy prices happen years apart, with no changes in between. For example, Saudi Arabia implemented an episode of energy price reform in 2016 and then left prices unchanged for two more years until the next episode in 2018, as discussed in Chapter 3. In other countries, governments may stagger energy price increases within a shorter period. My database considers increases in regulated energy prices implemented in separate months as distinct reform episodes.<sup>17</sup> However, I consider episodes that occur in separate months but within a week of each

---

<sup>17</sup> The majority of episodes I found were separated by at least a month or more.

other (e.g., a set of prices increases on December 29, 2015, followed by a set of price increases on January 1, 2016) as a single episode.

### 4.3.2 Building a database of news articles and extracting information

My database was constructed by aggregating relevant news articles through a structured, manual search of three well-known news databases or aggregators: Nexis (2023a), ProQuest (2023), and Google (2023). These databases together host a vast number of news documents. For example, the Nexis (2023b) legal and news database hosts around 144 billion documents, adding new documents daily. These databases also provide various precision search capabilities.

Given the sheer number of documents in these databases, search command operators were combined to make each search more precise, allowing the searches to produce a manageable number of news articles (see Figure 16). These search commands include Boolean operators. For example, the search *gasoline AND price* produces a list of news articles in which both words must appear together in each document. I also combined such Boolean operators with specialized search operators (also known as precision search operators). For instance, in Nexis, the *HLEAD(gasoline AND price)* command was used to search for news articles that contained the terms “gasoline” and “price” in either the title or lead paragraph. Nexis also provides the *W/N* connector, which ensures that terms appear within *N* number of words of each other. An example of a search that I used in Nexis combined these operators is shown in Figure 16.<sup>18</sup> This search query instructs Nexis to search for news articles that mention, in either the title or lead paragraph, the country in question, in this example “India”, within seven words of different combinations of terms like “gasoline” and “subsidy” or “kerosene” and “price”. It also asks Nexis to ensure that the word “raise” or “hike” shows up in either the title or lead paragraph. This search produces an array of news articles with titles like “India hikes petrol, diesel prices”, which was published by Agence France Presse (2009).

---

<sup>18</sup> An example of a commonly used search in Nexis combined these commands as follows. Different values of *N* were tested, with values between 5 and 10 providing an appropriate balance between relevance, precision, and manageability in the number of search results.

```

HLEAD    (
            ( (India) W/7
              (
                ( (fuel) OR (gasoline) OR (petrol) OR (diesel) OR (kerosene)
                  OR (LPG) OR ("cooking gas") OR (electricity) OR (power) )
                AND
                ( (price) OR (tariff) OR (subsid*) OR (rate) )
              )
            )
            AND
            ( (raise) OR (increase) OR (lift) OR (hike) OR (cut) )
          )

```

**Figure 16** Illustrative query used in Nexis to search for relevant news articles.

*Note: Precision operators are in bold, while Boolean operators are in italics. The asterisk after subsidy allows the search to find both the terms "subsidy" and "subsidies".*

All news articles obtained using such search queries were reviewed manually and saved in a database if they contained relevant content on the context or outcome of an energy subsidy reform, information that may support or contradict one of the six lessons that I synthesized from the literature, or further insights around the enablers of successful outcomes. To ensure consistency, the same manual search queries were repeated on a country-by-country and year-by-year basis. My final database contains over 3000 news articles, covering over 400 distinct episodes of energy subsidy reform stretching from 1995 to 2022 across 44 countries.

Each news article in the final database was reviewed manually against a common spreadsheet that was developed that contained columns for key details to find in each news article. Each row in this spreadsheet represented a distinct episode of energy subsidy reform. Often, a series of news articles published before and after a government implemented an episode of energy subsidy reform were reviewed in tandem to extract further details about that episode (see Table 22 in Section 4.4 for an illustrative example of a series of news articles). These details were then coded into the spreadsheet. Quantitative information like the size of the gasoline or diesel price increase was pulled into the spreadsheet, providing not only an indication of the magnitude of the fuel price

increases but also the extent of fuels affected in each episode. Other information, like whether compensation was used, or whether stakeholders were consulted, was also added to the spreadsheet when available. Furthermore, each news article was reviewed against the six lessons that I synthesized from the literature (as discussed in Section 4.2), and notes were taken if there was any information in each news article that supported, contradicted, or added further nuance to those six lessons. This process was consistently followed for extracting information from all the news articles across all 44 countries.

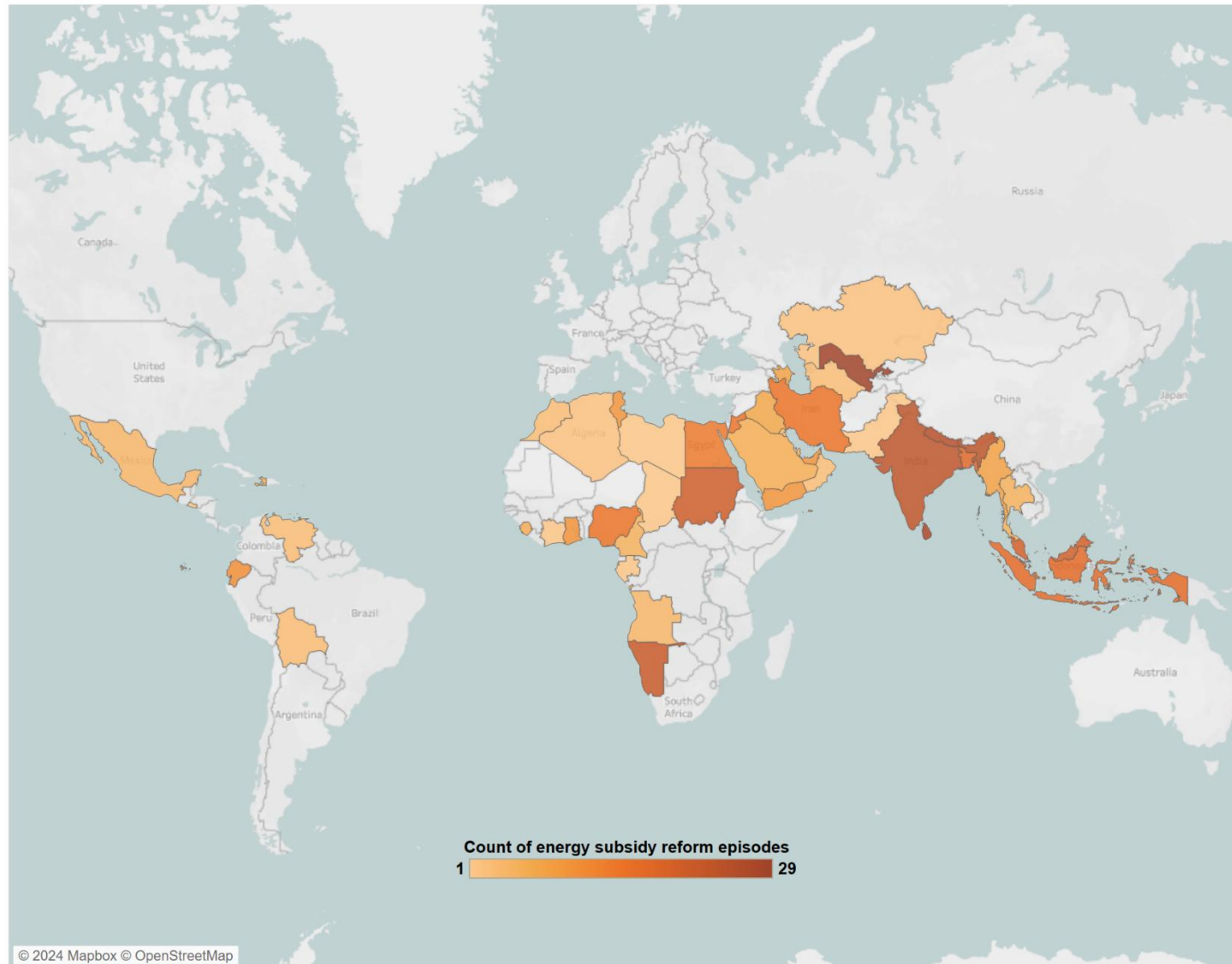
The 44 countries were selected based on two factors: First, a search for major episodes of energy subsidy reform was conducted without specifying the country, producing a list of countries in which major episodes occurred and were reported on in the online news databases. This list of countries included developing countries in which energy prices were subsidized and regulated by the government. This list was then compared to the list of countries in which the IEA (2023, 2024) finds consumer energy subsidies. The IEA's energy subsidy dataset includes 49 countries, but several countries (e.g., Austria and France) on their list were reported to have zero consumer energy subsidies in most years and were thus excluded from the comparison. Excluding such countries, my final list of 44 countries includes all the countries with non-zero consumer energy subsidies listed in the IEA's (2023, 2024) energy subsidy datasets, plus additional countries in which major episodes of energy subsidy reform took place between 1995 and 2022 according to the online news databases. These additional countries are Cameroon, Côte d'Ivoire, Chad, Haiti, Jordan, Morocco, Myanmar, Namibia, Nepal, Sierra Leone, Sudan, Tunisia, and Yemen.

### **4.3.3 Challenges with data collection using online news databases**

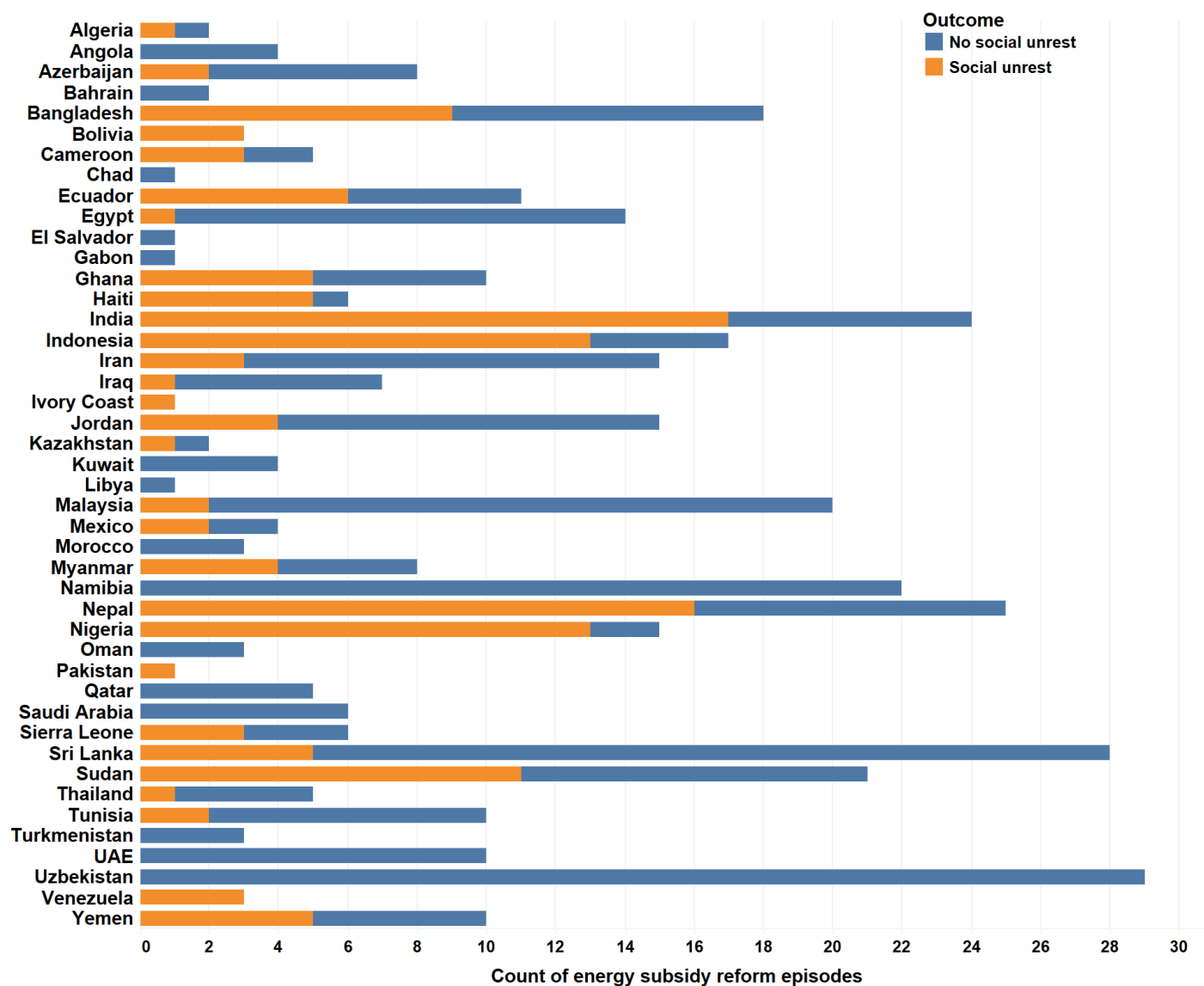
It is important to acknowledge some of the challenges associated with data collection using online news databases. One challenge relates to coverage discrepancies across different news databases. Buntain et al. (2023) compared several news databases, including Nexis, Factiva, Google News, NewsBank, and ProQuest, and they found “considerable differences in number of stories, geographic reach, media type and coverage of a specific news event.” To mitigate this issue, I used three databases (Nexis, Google, and ProQuest) in my searches, but there remain other databases that were not used in the construction of my dataset that may have provided additional geographic reach. Another source of bias relates to the extent of news media coverage of an event. Studies have shown that “media exhibit significant regional biases, disproportionately

cover large urban areas or areas with wire service offices, and report events with large numbers rather than small” (Woolley, 2000). However, research in this area also suggests “that ‘hard facts’ are less subject to bias than are interpretations of the meaning of the event or the motives of participants” (Woolley, 2000). In this thesis, the focus is on searching for facts around the implementation and context of energy subsidy reform rather than searching for underlying meanings. Another challenge relates to the replicability of data collection using online news databases (Karstens et al., 2023). To address some of these replicability issues, Karstens et al. (2023) recommended best practices when using online news databases to collect data. Their best practices include specifying which databases are utilized, including the search strings that were used, including information on how articles were processed or analyzed, and keeping up to date on the terms of use of the databases. Many of these best practices were followed in the construction of this dataset.

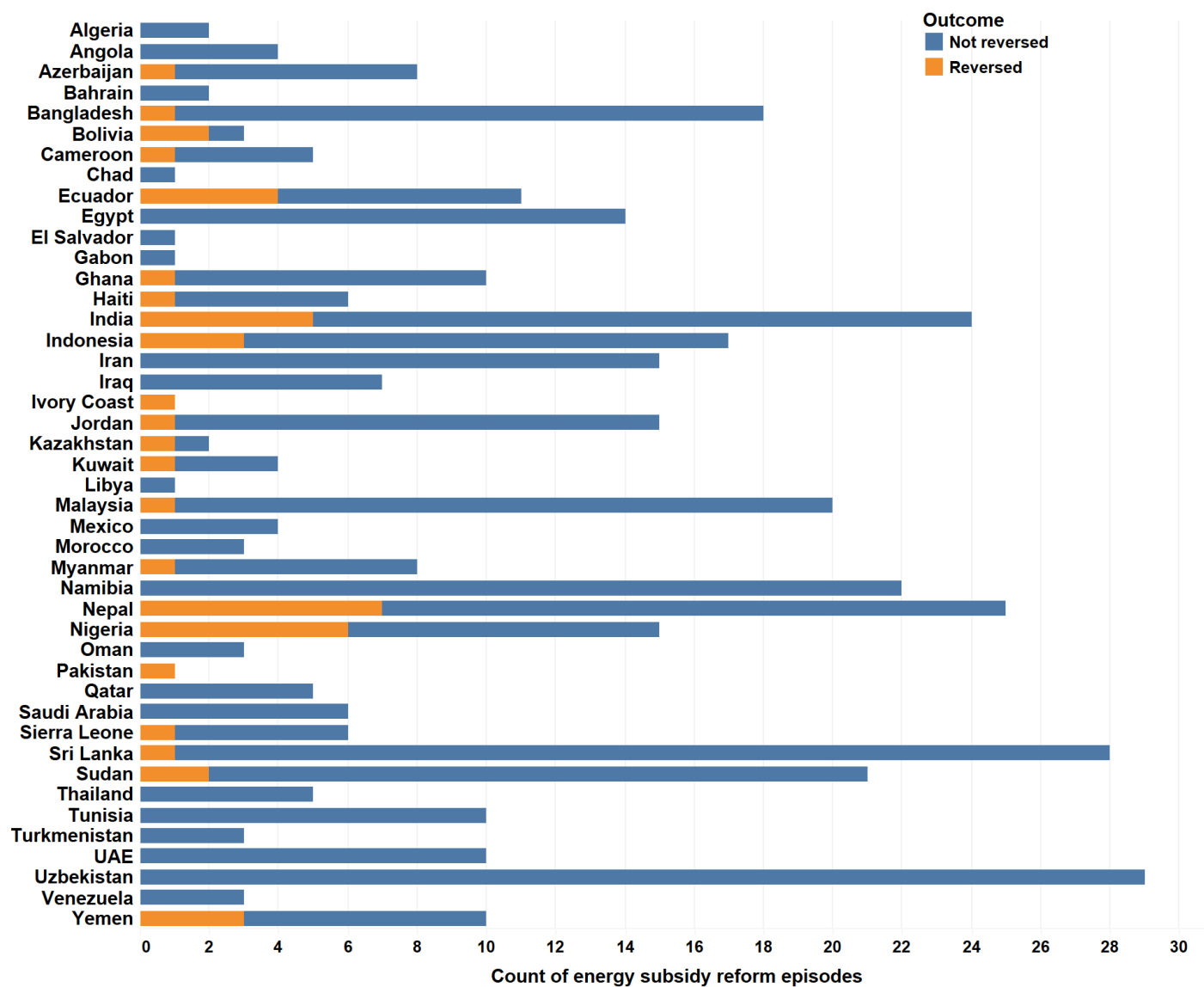
The results of building this dataset are summarized in Figure 17, which maps the number of episodes found by country, while Figure 18 and Figure 19 respectively break down the number of episodes by the occurrence of social unrest and reversal.



**Figure 17** Map of energy subsidy reform episodes found through the news-content-based search for the 1995-2022 period.



**Figure 18** Energy subsidy reform episodes disaggregated by unrest outcome.



**Figure 19** Energy subsidy reform episodes disaggregated by reversal outcome.

## 4.4 Results and Discussion

### 4.4.1 What does the database reveal about the six lessons from the literature?

#### 4.4.1.1 *Preparing a comprehensive strategy*

I searched my database for examples of ambitious energy subsidy reforms succeeding because of a well-prepared strategy (see Table 22 for an example about Nigeria of how insights were drawn from the content of a series of news articles). Iran's successful reform in 2010 provided one such example. This episode encompassed several-fold increases in food, fuel, and electricity prices (Agence France Presse, 2010a). The Iranian government ensured that implementation was not rushed, increasing prices only after finalizing critical decisions around compensation and making arrangements for implementation (Agence France Presse, 2010b, 2010c). The government also positioned the reform as part of a broader transformation (Karimi, 2010; Guillaume et al., 2011), clarifying its objective of "economic surgery". The government communicated the reforms to the public before implementation, ensuring no surprises, and simultaneously launched a comprehensive compensation scheme, with cash distributed to over 80% of all Iranian households. The use of compensation illustrates the government's understanding of its citizens' expectations, while the level of compensation points to an impact assessment. Despite the remarkable increase in energy prices, the government's well-prepared strategy appeared to pay off, resulting in a successful outcome with no reported unrest and no reversal.

In contrast, Iran's unsuccessful energy subsidy reform in 2019 did not appear to benefit from a well-prepared strategy. With regard to national circumstances, the 2019 reform was implemented during a period of weak economic performance, as the Iranian economy contracted by 2.7% that year compared to growth of 5.8% during the successful episode in 2010 (World Bank, 2024a), with the 2019 sanctions likely contributing to Iran's poor economic circumstances (Gloystein, 2019). Furthermore, cash transfers in 2019 were not launched simultaneously with the price increases and instead were promised after the reform took place, indicating rushed implementation

(Agence France Presse, 2019; Salehi-Isfahani, 2019). The apparent lack of a carefully prepared strategy likely contributed to the unsuccessful outcome in 2019, with violent unrest and over a thousand reported deaths (Lipin, 2020), despite the energy price increases in 2019 being significantly smaller than those implemented in 2010.

Nigeria's 2012 energy subsidy reform provides another example of a lack of clear strategy. At the start of 2012, the Nigerian government doubled gasoline prices but did not implement compensatory measures (Africa News, 2012a; Deutsche Presse-Agentur, 2012a). In addition, Nigerian labour unions, key stakeholders that opposed the price increases, were not consulted, and the government's plans were described as "secretive", indicating a lack of communication and consultation (Africa News, 2011a; Africa News, 2011b). Given Nigeria's oil exports, its citizens consider fuel subsidies as a way to partake in the oil wealth (Africa News, 2011b), an expectation the Nigerian government did not account for. Corruption also appears to have played a significant role, as citizens believed that reducing corruption should take precedence over subsidy reform (McCulloch et al., 2021). The 2012 episode led to violent social unrest (Africa News, 2012c), which ultimately forced the government to reverse the reform (Africa News, 2012d). Had Nigeria prepared an effective reform strategy, which would ideally have considered its position as an oil exporter, its citizens' expectations, and the need for compensation, and integrated a thorough communication program, it may have avoided the occurrence of violent unrest and a policy reversal.

**Table 22** *A list of news articles that were extracted before, during, and after Nigeria's energy subsidy reform episode implemented on January 1, 2012.*

| <b>News article title<br/>(date published)</b>                                         | <b>Database<br/>obtained from</b> | <b>Extracted insights</b>                                                                                                                                                                                                              | <b>Reference</b>                    |
|----------------------------------------------------------------------------------------|-----------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------|
| Nigeria; Forget About Fuel Subsidy Removal, Govt Urged (October 18, 2011)              | Nexis                             | The article highlights how labour unions in Nigeria were against any future reform and their conditions to the government for deregulation, such as the introduction of mitigating measures.                                           | Africa News (2011a)                 |
| Nigeria; The Unanswered Questions on Fuel Subsidy Removal (December 21, 2011)          | Nexis                             | The article discusses the debate around energy subsidy reform, describing the government's plans as "secretive and ambiguous", while pointing to a lack of effective communication. Palliative measures are also discussed.            | Africa News (2011b)                 |
| Nigeria; The Instinctive Opposition to Fuel Subsidy Removal (December 29, 2011)        | Nexis                             | The article discusses how subsidy removal became "imperative" for the government, highlighting its cost and encouraging those who oppose the policy to think more carefully about the issue.                                           | Africa News (2011c)                 |
| UPDATE: Nigeria Starts Controversial Measure to Remove Fuel Subsidy (January 01, 2012) | ProQuest                          | The article announces Nigeria's deregulation of the gasoline price, describing how the gasoline price was suddenly increased and discussing the responses of Nigeria's two main labour unions, which issued directives for protests.   | Dow Jones Institutional News (2012) |
| Nigeria; Fuel Price Soars 116 Percent (January 02, 2012)                               | Nexis                             | The article details the percentage increase in the gasoline price, highlighting how the increase was conveyed by Nigeria's Petroleum Products Pricing and Regulatory Agency. It also reviews a range of reactions across stakeholders. | Africa News (2012a)                 |
| Police break up Nigeria fuel price hike protests (January 03, 2012)                    | Nexis                             | The article reveals that the energy subsidy reform triggered protests. It states that the protestors demanded the policy's reversal, while Nigeria's president defended the reform, promising it would help boost infrastructure.      | Deutsche Presse-Agentur (2012a)     |
| Nigeria; Jonathan Slashes Govt Spending After Fuel Price Hikes (January 08, 2012)      | Nexis                             | The article discusses the President's initial response to the protests, which included cuts in the basic salaries of all officeholders in the executive government and the launch of a mass transit program to improve mobility.       | Africa News (2012b)                 |
| Nigeria; Fuel Subsidy – 11 Killed in Bloody Protests (January 10, 2012)                | Nexis                             | The article describes the casualties that resulted from clashes between police and protestors, underscoring how some of the protests turned violent.                                                                                   | Africa News (2012c)                 |
| Nigeria; Protests Suspended as Govt Cuts Fuel Price (January 16, 2012)                 | Nexis                             | The article discusses the President's partial reversal of the reform and his plan to curb corruption in the oil and gas sector before considering any future energy subsidy reforms.                                                   | Africa News (2012d)                 |
| Nigeria partially reinstates fuel subsidy (January 16, 2012)                           | Nexis                             | The article discusses the President's reversal of the reform, highlighting how the President met with labour union leaders for further talks but could not yet agree on future deregulation plans.                                     | Rice (2012) [Financial Times]       |

#### ***4.4.1.2 Ensuring that the timing is appropriate***

I searched the database to better understand how timing may influence energy subsidy reform outcomes, and the various factors that policymakers should consider when deciding on the appropriate time for reform. As illustrated by Iran's contrasting reform experiences in 2010 and 2019, economic circumstances play a vital role. Countries that are experiencing robust economic growth appear more likely to achieve a positive outcome compared to contracting economies. Governments with growing economies likely have better political support from the public, who may be more willing to accept such government interventions.

The readiness of complementary policies is another important factor for selecting an appropriate time for launching reforms. Ideally, countries should prepare mitigating measures such as compensation schemes before raising energy prices. For example, the Angolan government announced fuel price deregulation in 2016 (Kojima, 2016) but abandoned its plans given the absence of mitigating measures – a decision that may have prevented the occurrence of social unrest at the time. It was later reported that the Angolan government was working to prepare a cash-transfer scheme (Vollgraaf, 2019, CE Noticias Financieras English, 2022c), and would only increase energy prices once that scheme was operational. Saudi Arabia provides another example of waiting for complementary policies to be ready. In 2016, the Saudi government quickly implemented a wave of reform in response to falling international oil prices and its fiscal deficit. However, the extent of the price increases on household energy products like residential electricity was limited, as shown in Chapter 3. In Saudi Arabia, electricity is primarily consumed in buildings to provide cooling, an essential energy service given its hot climate. Over the subsequent two years, the Saudi government assessed the impacts of further reforms and prepared a comprehensive cash transfer scheme. The Saudi government implemented its 2018 reform, which involved a tripling of the residential electricity price, only when all supporting measures were put in place (Fiscal Balance Program, 2017). As Obaid (2017) reported, the Saudi government ensured that beneficiaries received cash transfers weeks in advance of the sharp gasoline and residential electricity price increases at the start of 2018.

Even what appear to be minor factors, such as weather conditions, may influence reform outcomes and need to be accounted for when selecting an appropriate time for implementation. For example, in November 1997, the Algerian government approved a 35% increase in the price of LPG, a crucial fuel used by households for both cooking and heating (Agence France Presse, 1997; Inter Press Service, 1997). This significant increase did not trigger unrest and was not reversed. According to the CCKP (2023), the average temperature in Algeria in November 1997 was 19.0 °C. In January 2005, during the peak of a frigid winter, the government increased LPG prices by around 18% after seven years of no price changes (Belkadi, 2005). According to the CCKP (2023), the average temperature in Algeria in January 2005 was 11.1 °C, the coldest recorded month in Algeria between 1990 and 2021. The harshness of the winter, alongside other factors, may have contributed to triggering protests, which were mainly in the cold mountainous regions of Algeria where LPG is used for heating (Belkadi, 2005). In contrast to Algeria, Saudi Arabia's massive residential electricity tariff increases in 2018 were implemented during winter, when Saudi households' electricity bills are lowest. The Saudi government may have been aware of the potential negative impacts of implementing such a reform during summer, when household electricity bills are at their peak due to massive cooling demand.

#### ***4.4.1.3 Communicating and consulting with stakeholders***

I searched my database for examples of how communication can influence reform outcomes, finding differences across countries in the importance, role, and types of stakeholders that governments need to communicate and consult with.

Communicating effectively with the general public appears to contribute to successful outcomes. Malaysia provides one such example. Throughout the 2010s, the Malaysian government ensured that the public was continuously informed about the cost of subsidies by posting at gas stations and on electricity bills the subsidized energy prices, what prices would have been without subsidies, and the cost incurred by the government (Bridel and Lontoh, 2014). The government also took out advertisements in various media publications where it highlighted the massive costs of subsidies, and it ran multiple online and Short Messaging Service (SMS) polls to inform and obtain

feedback from the public (Hassan, 2010). Moreover, the government allowed the public to share further feedback on planned reforms through other avenues, underscoring its willingness to listen. For example, the government held a Subsidy Rationalisation Lab Open Day in 2010, allowing the public to give direct feedback on its upcoming reform plans (Malaysia General News, 2010; Mustaza, 2010), feedback that led the government to adopt a more gradual approach (Taking, 2010). Malaysia's communication with the public likely contributed to its consistently successful reforms throughout the 2010s.

Civil society, which includes non-governmental organizations and unions, is another key external stakeholder. In Nigeria, energy subsidy reform has been characterized as a battle between the government and unions (Akanle et al., 2014). Throughout the 2000s and 2010s, these unions drove protests across Nigeria in response to reforms, in some cases successfully forcing a reversal (Rice, 2012). For example, at the end of 2011, against a backdrop of high international oil prices, Nigerian unions outlined their conditions to the government for accepting any future price increases (Africa News, 2011a). However, without consultation, the government doubled gasoline prices at the start of 2012 (Dow Jones Institutional News, 2012), triggering protests by those unions (Deutsche Presse-Agentur, 2012a), which turned deadly (Africa News, 2012c). The unions only called off the protests when the government partially reversed the gasoline price increase. Nigeria's energy subsidy reform in 2012 may have been successful had the government consulted with unions, addressed their concerns, and made the required compromises before implementation.

Opposition parties are another stakeholder that can influence reform outcomes. In South Asian countries like India and Bangladesh, opposition parties have often played the leading role in organizing protests (Associated Press International, 2003; Agence France Presse, 2004a; Agence France Presse, 2010d), in contrast to countries like Nigeria, where civil society played that role instead (Deutsche Presse-Agentur, 2012a). Opposition parties can either cooperate with the government during reform or use it to undermine the government, hoping to be elected to power (Moury and De Giorgi, 2015; Palau et al., 2015). Governments can involve opposition parties in the consultation

process, but there may be a limit to how much control they have over their response, given the political conditions and circumstances in each country.

#### ***4.4.1.4 Implementing energy subsidy reforms gradually***

My database provides numerous examples of drastic energy price increases leading to policy reversals. For example, in December 2010, the Bolivian government implemented the largest fuel price increases in at least two decades, resulting in widespread rioting (Agence France Presse, 2010e), which ultimately led the government to fully reverse the price increases (Al Jazeera, 2011). In August 2022, Bangladesh implemented unprecedented increases in fuel prices (Bdnews24.com, 2022), which led to widespread protests, with the government responding with price cuts (The Financial Express, 2022a; The Daily Star, 2022). Both Bangladesh and Bolivia experienced unsuccessful outcomes when implementing large energy price increases. In contrast, both countries had implemented successful reforms in the past when the energy price increases were smaller. Malaysia provides a successful example of gradually reforming energy subsidies. Between 1995 and 2022, my database reveals 20 distinct episodes of reform in Malaysia. The only episode that led to some minor protests occurred in June 2008 (Prince Rupert Daily News, 2008) and involved the largest increases in fuel prices among the 20 episodes. The remaining 19 episodes, all of which involved small energy price increases, were found to be successful. Staggering reforms by fuel could also contribute to positive outcomes, an approach that India has used. In 2010, India deregulated gasoline prices first (Agence France Presse, 2010f), before deregulating diesel prices between 2013 and 2014 (Agence France Presse, 2013; Chaturvedi and Sahu, 2014). It then started deregulating LPG and kerosene prices in 2016 (The Hindustan Times, 2016).

While the fact that smaller and more gradual price increases are more likely to be accepted than larger ones may seem obvious, many governments can be forced into implementing significant energy price increases when economic conditions change rapidly. If governments are forced to implement large energy price increases, the other factors that contribute to successful outcomes must be incorporated into their plans to offset the impact of such large increases. Examples of reforms succeeding despite large

energy price increases include Iran's reform in 2010 and Saudi Arabia's reform in 2018, likely due to the other enablers that both governments incorporated during implementation.

#### ***4.4.1.5 Launching compensation schemes and other complementary policies***

My database provides numerous examples of compensation contributing to successful outcomes. In 1998, the Indonesian government implemented significant increases in energy prices without compensation (Agence France Presse, 1998a), triggering violent protests that ultimately led to a policy reversal and the president's resignation (The Associated Press, 1998; Agence France Presse, 1998b). In October 2005, the Indonesian government attempted even larger energy price increases (Agence France Presse, 2005a), but they were launched alongside a cash transfer scheme to cushion the impacts on lower-income households. Unlike past reforms in Indonesia, which generally led to widespread rioting and reversals, the October 2005 protests were described as "small by Indonesian standards" (Agence France Presse, 2005a), and they were not reversed. As noted by Beaton and Lontoh (2010), "analysts credited this [reduced opposition] to the government's decision to compensate poor households."

I find that not all compensation schemes are equally effective, as there can be significant variation in their design. The share of the population benefiting from compensation is one crucial design consideration. Iran's successful energy subsidy reform in 2010 benefited from a comprehensive cash transfer scheme, as around 60.5 million Iranians – over 80% of the population – received cash transfers (Agence France Presse, 2010a; World Bank, 2024a). Saudi Arabia's successful reform in 2018 also involved comprehensive compensation, with over 60% of the Saudi population benefiting (Argaam, 2019; GASTAT, 2024).

The timing of compensation also appears to influence its effectiveness. The successful reforms in Iran in 2010 and Saudi Arabia in 2018 involved compensation being given before raising energy prices (Trend Daily Economic News, 2010; Obaid, 2017). In contrast, promising compensation after raising energy prices appears less likely to lead to a successful outcome, allowing protests to potentially break out before compensation is received. In 2019, despite implementing relatively minor price increases, violent

protests were triggered in Iran (Bozorgmehr, 2019) when compensation was promised in ten days. Similarly, widespread protests took place in Jordan in 2012 after the government increased energy prices and promised compensation within ten days (EIU, 2012). Nevertheless, although delayed compensation may not be as effective at preventing social unrest, it may help calm it down, thus preventing the unrest from escalating to the point that forces the government to reverse the reform.

The timing and comprehensiveness of compensation are two design factors that feed into the measure's credibility, which is essential for public acceptance. Speaking about his experience with energy subsidy reform and compensation, Ibrahim Saif, the former minister of energy in Jordan in the 2010s, discussed his team's extensive efforts "to establish credibility that we were willing to compensate" (IMF, 2017).

Another crucial element relates to the form of compensation, which includes cash transfers, in-kind transfers, salary increases, subsidies to other goods and services, or reinvestment of government revenues/savings. My review suggests that cash transfers may be most effective, as this form of compensation led to successful outcomes during the ambitious reforms implemented by Iran in 2010, Saudi Arabia in 2018, and Indonesia in 2005, as discussed previously. The effectiveness of cash transfers is in line with theoretical and empirical work (Hidrobo et al., 2014; Alderman et al., 2018). My review also suggests that salary increases may be effective but make it challenging for governments to ensure sufficient coverage since salary increases target only public sector workers, with many lower-income citizens in the private sector and the unemployed receiving no compensation. For example, in 2010, the Bolivian government raised fuel prices and promised substantial salary increases (Mapstone, 2010; Agence France Presse, 2010d). The reform triggered protests that forced a reversal (Flores, 2010). The coverage of the Bolivian government's compensation would have likely been better had it given cash transfers to all lower-income citizens, which in turn would have likely contributed to a better outcome. I also find evidence that mixing different forms of compensation could lead to a positive outcome if coverage is sufficient. For example, in 2000, the Ecuadorian government raised fuel prices sharply despite a history of energy-price-related unrest (OxResearch Daily Brief Service, 2000). To alleviate negative

impacts, the government increased salaries in the public sector and the economy-wide minimum wage, pensioner payments, disabled persons' allowances, and social safety cash transfers (OxResearch Daily Brief Service, 2000), with such comprehensive compensation contributing to a successful outcome.

In addition to compensation, other policies can complement energy subsidy reform. For example, governments can use energy efficiency regulations to improve energy efficiency and offset the effect of higher energy prices on the cost of services like heating and cooling (IEA et al., 2010; Alfawzan and Gasim, 2019). Energy subsidy reform also appears more likely to succeed when positioned as part of a broader economic transformation alongside positively perceived reforms. For example, in Saudi Arabia, energy price reform was part of the government's Fiscal Balance Program (2017) under Saudi Vision 2030 (2016), an overarching strategy for social and economic transformation. Saudi Arabia's 2018 reform was implemented alongside an anti-corruption campaign (Al Arabiya, 2018), a lift on the ban on women driving (Hutcherson, 2018), and reforms to empower women (Saleh and Malibari, 2021). The positive impacts of these interventions likely contributed to the successful reform outcome in 2018.

#### ***4.4.1.6 Moving towards automatic or market-based pricing***

My database provides numerous examples of countries successfully transitioning to automatic or market-based energy pricing and countries failing to do so.<sup>19</sup> For example, the United Arab Emirates (UAE) successfully deregulated gasoline and diesel prices in August 2015 by adopting an automatic pricing mechanism while establishing a committee to oversee its new mechanism (Emirates News Agency, 2015). In contrast, Ecuador deregulated fuel prices in May 2020 (Zaldumbide, 2020), but was forced to freeze prices when the October 2021 price increase triggered protests (Valencia, 2021). The success of this transition likely depends on a myriad of factors, including those discussed previously, such as compensation.

---

<sup>19</sup> I use the term deregulation to describe a country transitioning to an automatic pricing mechanism or market-based pricing.

Following energy price deregulation, price smoothing can be used to protect consumers from sharp increases in international fuel prices, potentially contributing to a successful transition. Price smoothing can be done using price bands, price floors and caps, or stabilization funds. For example, after deregulating gasoline prices in 2020, Ecuador established a price band to limit monthly price variations to  $\pm 5\%$  (CE Noticias Financieras English, 2020). While this appeared to work for a year, protests eventually broke out in the face of steadily rising international oil prices, forcing a reversal. Saudi Arabia also deregulated gasoline prices in 2020 (The Saudi Gazette, 2020; Gasim and Aldubyan, 2020), but unlike Ecuador, chose to place a cap on domestic prices a year later when the government determined that international fuel prices had risen too high (Neriem, 2021; ArabianBusiness, 2022). Stabilization funds have also been used by countries like Cameroon, Chile, and Thailand (Vagliasindi, 2013; Kojima, 2016), but these countries faced challenges in effectively operating such funds, as noted by Kojima (2016). While these tools could be effective at smoothening volatility, they may also lead to the re-emergence of subsidies in the long run if they are not used transiently (Kojima, 2016), so further evidence is needed to better understand which tools may be most effective in which countries and under which circumstances.

#### **4.4.2 What additional lessons does the database provide?**

In addition to providing evidence corroborating the six lessons drawn from the literature and adding further nuances, my analysis of the database presented in this study yields other insights for policymakers. First, I find that some countries may not have the right capabilities or circumstances to reform energy prices successfully, like a country with a contracting economy, high unemployment, and no capacity to implement compensation. For such a country, reform is more likely to fail, so it may be better to explore alternative policies until the government can improve its institutional capacity or national circumstances change.<sup>20</sup>

---

<sup>20</sup> Selecting a policy instrument to achieve a certain policy objective generally depends on the cost effectiveness of the instrument, its ease of implementation, and its political feasibility, among other factors. While energy price reform can be one of the most cost-effective policy instruments, it may also

My review points to the importance of implementing energy subsidy reforms successfully at the first attempt. I find numerous examples of unsuccessful first attempts that appear to have made future attempts even more challenging. In Bangladesh, violent protests erupted in 1997 following energy price increases (Agence France Presse, 1997). Multiple Bangladeshi governments subsequently attempted further reforms, with attempts in August 2000 (Deutsche Presse-Agentur, 2000), September 2005 (Agence France Presse, 2005b), and August 2022 (Asian News International, 2022) leading to widespread protests. In Indonesia, the 1998 reform led to riots, a reversal, and the president's resignation (Agence France Presse, 1998a, 1998b; Facts on File World News Digest, 1998). Subsequent attempts by Indonesian governments in October 2000 (The Associated Press, 2000), June 2001 (Asian Wall Street Journal, 2001), January 2003 (Xinhua General News Service, 2003), and March 2012 (Deutsche Presse-Agentur, 2012b) also led to protests and reversals. In Nigeria, the attempt to remove fuel subsidies in June 2000 sparked riots and caused the government to reinstate subsidies (Facts on File World News Digest, 2000; Oyo, 2000). Subsequent attempts by Nigerian governments in January 2002 (Africa News, 2002), June 2003 (Africa News, 2003), August 2005 (Africa News, 2005), and January 2012 (Africa News 2012a-2012d) also led to protests and reversals. It appears that once protesters succeed in forcing their government into a reversal, they may be more likely to try to do so again in response to future reforms.

My review indicates the importance of protecting lower-income households by keeping fuels such as kerosene and LPG subsidized while deregulating other fuels. Kerosene and LPG are essential to lower-income households, making them the most politically challenging to reform. In India, between 2004 and 2010, the government implemented nine energy subsidy reforms, including in June 2004 (Associated Press International, 2004; Devraj, 2004), November 2004 (Agence France Presse, 2004b), June 2005 (BBC Monitoring South Asia, 2005), September 2005 (The Hindustan Times, 2005), June

---

not be politically feasible, so some governments may be better off picking an alternative instrument. For example, if the government's objective is to improve the fiscal balance, one alternative policy could be raising income taxes for certain groups or introducing a low value-added tax. If the objective is to reduce emissions, a government may use regulatory instruments to achieve that goal instead of energy subsidy reform.

2006 (BBC Monitoring South Asia, 2006), February 2008 (Oil Daily, 2008), June 2008 (Badam, 2008; MacRae, 2008), July 2009 (Agence France Presse, 2009), and June 2010 (Kazmin, 2010). Among these nine episodes, gasoline and diesel prices were hiked every single time, LPG prices were hiked four times, and kerosene prices were hiked once in June 2010 – the only one episode that involved all four fuels and led to widespread protests (Asian News International, 2010). A recent study by Schaffitzel et al. (2020) on Ecuador validates these findings on the sensitivities associated with LPG and kerosene, in which the authors interviewed multiple experts that agreed that “if LPG [subsidy] is touched, the [Ecuadorian] government will fall.” Moreover, continuing to subsidize LPG and kerosene may contribute to environmental sustainability, as many lower-income households face a choice between using biomass (e.g., charcoal or firewood), LPG, and kerosene. Wijayatunga and Attalage (2002) found that substituting biomass with kerosene and LPG reduces CO<sub>2</sub> emissions by up to 46% from household cooking in Sri Lanka. Raising LPG and kerosene prices can thus encourage an unwelcome switch to more emission-intensive biomass, which produces more CO<sub>2</sub>, nitrogen oxides, and carbon monoxide emissions (Wijayatunga and Attalage, 2002; Olabisi et al., 2019). In summary, governments can increase the likelihood of delivering a successful energy subsidy reform for fuels like gasoline and diesel by continuing to subsidize essential fuels like kerosene or LPG, and in doing so may also unlock further environmental and health benefits by preventing lower-income households from switching back to biomass.

My review also looked at the actions a government can take after its attempt at energy subsidy reform leads to protests. I find that partial reversals can be used to hold on to part of the fiscal, economic, health, and environmental benefits of reform while demonstrating to stakeholders the government’s willingness to listen and compromise. I find many instances of effective partial reversals. In 2005, the Bolivian government raised fuel prices but partially rolled back the diesel price increase to compromise with public transport operators (Lapper, 2005). In 2008, Cameroon faced one of the largest episodes of unrest after it increased fuel prices (BBC Monitoring Africa, 2008; Amin, 2013). The government agreed to partially reverse the gasoline and kerosene price increases (Africa News, 2008a, 2008b). Protests initially continued due to other political

decisions (Deutsche Presse-Agentur, 2008), but the unrest soon calmed down (Africa News, 2008c). In Côte d'Ivoire, a partial reversal was also used to calm protests following a reform in July 2008 (Agence France Presse, 2008). The government's response involved partial cuts to diesel and kerosene prices alongside reductions to minister salaries and increases in allowances for civil servants (Africa News, 2008d). In Nigeria, partial reversals have been frequently used to compromise with protest-leading unions. In 2012, Nigeria raised gasoline prices from 65 to 141 Naira per litre, triggering violent protests (Africa News, 2012a, 2012b, 2012c), which came to an end when the government cut gasoline prices to 97 Naira per litre (Africa News, 2012d). The Nigerian president also promised to audit the Nigerian National Petroleum Corporation to eliminate corruption, a key concern for stakeholders, demonstrating his government's willingness to listen and compromise (Africa News, 2012d).

## **4.5. Conclusion**

Policymakers worldwide continue to face challenges in achieving successful reform outcomes. These challenges are preventing efforts around the world to implement further energy subsidy reforms, which explains why the scope for further subsidy reform remains enormous. In the latest report by the IMF on global fossil fuel subsidies, Black et al. (2023) estimated pre-tax ("explicit") subsidies in 2022 at around 1.3 trillion USD – over 1% of global gross domestic product. According to the IMF, Saudi Arabia alone accounts for 10% of their global estimate. The IEA obtained a similar estimate for global fossil fuel subsidies in 2022, estimating the total to be over 1.1 trillion USD and noting that this was a record level for global fossil fuel subsidies since the IEA started tracking them (IEA, 2024).

Given the drivers for energy subsidy reform and the enormous potential but persistent barriers to successful implementation, I reviewed the literature to understand better the factors contributing to successful outcomes. I synthesized six lessons from the literature: 1) preparing a comprehensive strategy, 2) ensuring that the timing is appropriate, 3) communicating and consulting with stakeholders, 4) implementing reforms gradually, 5) launching compensation schemes and other complementary policies, and 6) moving towards automatic or market-based pricing. However, these

lessons from the literature were mainly drawn from reports that relied on the past experiences of IGOs with a smaller group of selected countries. The IGOs' experiences represent only a tiny subset of all past attempts at reform over the last few decades. To expand the temporal and geographical scope of countries and episodes from which I can draw lessons, I constructed a database with over 3000 news articles covering over 400 energy subsidy reforms implemented worldwide between 1995 and 2022. I then leveraged this original database to expound on the lessons from the literature and draw additional insights.

With regards to the first lesson, I found contrasting experiences that highlighted the value of preparing a comprehensive strategy. For example, Iran's successful energy subsidy reform in 2010, which was rooted in a carefully prepared strategy, was juxtaposed with its unsuccessful reform in 2019, which did not benefit from the same preparation. As for the second lesson, I highlighted several factors that need to be considered when deciding on an appropriate time for reform, including the weather, a factor that can have important consequences given households' essential needs for cooling or heating services. With respect to the third lesson, I investigated examples of effective communication and highlighted the range of stakeholders – and their varying importance across countries – that governments need to engage with. As for the fourth lesson, I found extensive evidence reinforcing the vital role of gradual price increases. With regards to the fifth lesson, I highlighted the importance of compensation design, specifically the roles of coverage and timing, for promoting a successful outcome. Finally, I explored numerous examples of countries successfully transitioning to automatic or market-based energy pricing and countries failing to do so, discussing some of the tools those countries used to minimize volatility following reform.

Further conclusions emerged from the analysis of the dataset. I found that some countries may not have the capabilities or circumstances needed to reform energy prices successfully. Therefore, it may be better for such countries to explore alternative policy options to achieve their goals – at least until their institutional capacity improves, or circumstances change. My analysis pointed to the importance of implementing energy subsidy reforms successfully at the first attempt. I found numerous examples of

unsuccessful first attempts that made future attempts even more challenging. I also discussed how reforms affecting a subset of energy products, but excluding essential fuels like LPG and kerosene, may be more likely to succeed while also potentially improving environmental outcomes for lower-income households. Finally, I examined the actions a government can take after its attempt at energy subsidy reform leads to protests, finding that a government can use partial reversals to hold on to part of the benefits of reform while demonstrating to stakeholders its willingness to listen and compromise.

In addition to qualitative reviews of past energy subsidy reforms, including the one in this chapter, quantitative research is also needed to measure how different factors and national circumstances influence the probabilities of a successful or unsuccessful outcome. To the best of my knowledge, only two papers have applied quantitative tools to this issue: Natalini et al. (2020) and McCulloch et al. (2022). However, both found conflicting results on the impact of international oil prices on energy-related unrest, and their datasets included relatively few energy subsidy reform episodes. More quantitative research is needed to address this question.

# **Chapter 5: The Determinants of Successful Energy Subsidy Reforms: A Logistic Regression Analysis**

## **5.1 Introduction**

This chapter seeks to further understand how policymakers in Saudi Arabia can implement energy subsidy reforms successfully. Chapter 4 encompassed a qualitative analysis that drew lessons from countries' past reform attempts using a news content database that I constructed. This chapter expands on that qualitative analysis by pulling quantitative data from news content and building a quantitative dataset on which I can apply data analysis tools to measure the effects of different factors and national circumstances on achieving a successful energy subsidy reform outcome.

As discussed in Chapter 4, I define an energy subsidy reform as a subsidy reduction resulting from an increase in the regulated price of an energy product that brings it closer to the level it would be in a deregulated market. I also define success as an outcome where energy subsidy reform does not lead to protests and/or is not reversed. As discussed, such a two-pronged definition of success has been used previously in the literature (Chelminski, 2018).

Despite the political importance of energy subsidy reform, the enormous potential for further reform globally, and the barriers to implementation, there is surprisingly very little quantitative research on what contributes to a successful reform outcome, as McCulloch et al. (2022) noted. There are currently two strands in the literature on energy subsidy reform outcomes. The first – and much larger – strand consists of qualitative reviews that drew lessons from countries' successful and unsuccessful past attempts at energy subsidy reform (e.g., UNEP, 2003, Viktor, 2009, Commander, 2012, Beaton et al., 2013, Clements et al., 2013; Vagliasindi, 2013, Atansah et al., 2017, Rentschler and Bazilian, 2017), as discussed in Chapter 4. The second strand, which relates more closely to this chapter, includes studies that quantified the impacts of different factors on the occurrence of riots following energy subsidy reform. To the best of my knowledge, there are currently only two such quantitative studies, both of which were published recently:

Natalini et al. (2020) and McCulloch et al. (2022) both applied logistic regression analysis to explore how different factors influence the occurrence of fuel-related riots.

More quantitative research is needed to inform policymakers on how different factors and national circumstances influence energy subsidy reform outcomes. The two studies by Natalini et al. (2020) and McCulloch et al. (2022) found conflicting results on the impact of international oil prices on fuel-related riots, and their datasets included relatively few instances of unsuccessful energy subsidy reforms (i.e., reforms that led to riots). This chapter addresses some of the major gaps in the literature by 1) building a comprehensive quantitative dataset that includes a much larger number of energy subsidy reform episodes and 2) applying logistic regression analysis to quantify the effects of a comprehensive set of relevant explanatory variables on the occurrence of a successful energy subsidy reform outcome.

Chapter 5 is structured as follows. Section 5.2 looks at the literature and compares the few existing quantitative studies on this topic. Section 5.3 details and describes my newly constructed quantitative dataset on energy subsidy reforms and outcomes, while also presenting the logistic regression methods. Section 5.4 presents and discusses the results of the regression analysis, while Section 5.5 concludes.

## **5.2 Literature Review**

As noted above, there are very few published quantitative studies that explore the determinants of energy subsidy reform outcomes. I focus on two key outcomes that can occur following energy subsidy reform. The first outcome relates to whether the reform is reversed or not, while the second outcome relates to whether the reform leads to social unrest or not. To the best of my knowledge, there exist no studies that quantified the determinants of energy subsidy reform reversal, and only two studies that quantified the determinants of energy-subsidy-reform-related social unrest: Natalini et al. (2020) and McCulloch et al. (2022). Both studies quantified how different explanatory variables influence the odds of ‘fuel riots’, which they defined as incidents of significant social unrest that occur in response to the reduction or removal of energy subsidies. Natalini et al. (2020) quantified the effects of one set of explanatory variables on fuel riots,

covering the 2005-2016 period, while McCulloch et al. (2022) quantified the effects of a different set of explanatory variables after extending the same dataset to 2018. The same manual Google search with a set of keywords was used to capture instances of fuel riots from news articles. Both Natalini et al.'s (2020) and McCulloch et al.'s (2020) data contain 59 instances of fuel riots. However, the explanatory variables in both studies' datasets, which were used to explain the occurrence of fuel riots in the regressions, differ completely. Natalini et al. (2020) included the international crude oil price, political stability, net fuel exports, and regime type as explanatory variables, while McCulloch et al. (2022) included the change in international and domestic gasoline prices, GDP growth, government effectiveness, corruption, civil freedom, anti-government movements, GDP per capita, and population as explanatory variables in one of their main models. Natalini et al. (2020) found that the international crude oil price has a statistically significant effect in increasing the odds of fuel riots, and that more politically stable or fuel-importing countries are less likely to have fuel riots (see Table 23). In contrast to the results of Natalini et al. (2020), McCulloch et al. found that the international gasoline price has no statistically significant effect on the occurrence of fuel riots. Instead, McCulloch et al. (2022) found that the growth in the domestic gasoline price increases the odds of fuel riots. Also, in contrast to Natalini et al. (2020), who found statistically significant coefficients on their other explanatory variables, McCulloch et al. (2022) found that only anti-government movements have a statistically significant effect in increasing fuel riots, with no statistically significant effects observed for any of the other explanatory variables. Table 23 highlights some of the conflicting results between Natalini et al. (2020) and McCulloch et al. (2022), which could stem from omitted variable bias, as each model contains a different set of explanatory variables. They could also stem from the use of different methods, or due to the extension of the dataset by two years by McCulloch et al. (2022), which increased the number of observations. (Since the number of instances of fuel riots was 59 in both studies' datasets, this suggests that McCulloch et al.'s (2022) larger dataset included only a larger number of observations of no fuel riots.)

**Table 23** *Estimated logistic regression models from the literature.*

| <b>Included explanatory variables</b>      | <b>Natalini et al.'s (2020)<br/>model 1</b> | <b>McCulloch et al.'s (2022)<br/>model 1</b> |
|--------------------------------------------|---------------------------------------------|----------------------------------------------|
| <i>International crude oil price</i>       | 0.756***                                    |                                              |
| <i>International gasoline price growth</i> |                                             | 4.022                                        |
| <i>Domestic gasoline price growth</i>      |                                             | 2.109**                                      |
| <i>GDP growth</i>                          |                                             | -0.0437                                      |
| <i>per capita GDP</i>                      |                                             | 0.145                                        |
| <i>population</i>                          |                                             | -0.0733                                      |
| <i>Population growth</i>                   |                                             |                                              |
| <i>Political stability</i>                 | 0.765***                                    |                                              |
| <i>Net fuel exports</i>                    | -0.405*                                     |                                              |
| <i>Regime type</i>                         | 0.119                                       |                                              |
| <i>Government effectiveness</i>            |                                             | -1.234                                       |
| <i>Extent of corruption</i>                |                                             | 3.743                                        |
| <i>Civil society freedom</i>               |                                             | 0.416                                        |
| <i>Anti-government movements</i>           |                                             | 0.813                                        |
| <b>Method</b>                              | Logistic mixed-effects model                | Fixed effects logit panel regression         |
| <b>Number of observations</b>              | 1769                                        | 3833                                         |

Given the conflicting results between Natalini et al. (2020) and McCulloch et al. (2022), it is difficult to draw takeaways for policymakers. However, the conflicting results do point to an important discussion about the determinants of fuel riots. In theory, fuel riots, as they have been defined, are driven by consumers protesting higher domestic fuel prices. However, Natalini et al. (2020) found that the international crude oil price is driving fuel riots. In countries with deregulated fuel prices, domestic fuel prices depend directly on the international oil price, as they are very closely correlated. However, this is not the case in many developing countries that regulate fuel prices (Kpodar and Imam, 2020). In such countries, the effect of the international crude oil price on domestic fuel prices can depend on whether the country is a net fuel importer or exporter. In the case of fuel-subsidizing oil exporters, domestic fuel prices are generally increased in the face of falling international oil prices to compensate for decreased oil export revenues (Fattouh et al., 2016). In contrast, fuel-subsidizing oil importers are more likely to raise domestic fuel prices when international oil prices are high, which tends to increase the fiscal burden from fuel subsidies (Vagliasindi, 2013). Additionally,

fuel-subsidizing countries generally face challenges in passing through changes in international oil prices to domestic fuel prices. For example, in Kuwait, gasoline prices had remained fixed for decades prior to the 2016 gasoline subsidy reform (Agence France Presse, 2016). Therefore, the international crude oil price in many cases may not reflect domestic fuel prices, so domestic prices should ideally be used as explanatory variables in the regression.

McCulloch et al. (2022) included both domestic and international gasoline prices as potential determinants of fuel riots and found that only the domestic gasoline price has a statistically significant effect on the odds of a fuel riot. However, McCulloch et al. (2022) looked at the relationship between fuel riots and only the domestic gasoline price. In many countries, it may be changes in the domestic prices of other fuels, such as diesel, kerosene, or LPG, that drive the occurrence of fuel riots, as discussed in Chapter 4. For example, the recent energy subsidy reform in Kazakhstan in 2022, which targeted LPG, led to widespread fuel riots (Al Arabiya, 2022; Sullivan, 2022). Attributing such fuel riots to gasoline prices and omitting LPG prices from the model can potentially lead to misleading results. Furthermore, McCulloch et al. (2022) omitted explanatory variables that Natalini et al. (2020) had found to be statistically significant, so there may potentially be issues with omitted variable bias.

In this chapter, I seek to address several of these identified gaps in the literature. First, I run a logistic regression analysis on two reform outcomes: the occurrence of social unrest and the occurrence of a reversal – the latter having not been looked at previously. Second, I run the regressions on an original quantitative dataset that I built from the news database that I presented in Chapter 4. My quantitative dataset captures many instances of fuel riots that were missing in the datasets used by Natalini et al. (2020) and McCulloch et al. (2022). My dataset has 142 instances of social unrest driven by energy subsidy reform compared to only 59 in both previous studies. Third, I include a comprehensive set of relevant explanatory variables in the regression models to minimize omitted variable bias. I do this by including both sets of explanatory variables used in Natalini et al. (2020) and McCulloch et al. (2022). My dataset also contains important explanatory variables that had not been looked at previously,

including increases in the domestic prices of diesel, LPG, kerosene, and residential electricity, and whether compensation was used during the reform.

## **5.3 Data and Methods**

### **5.3.1 Dataset construction**

The quantitative dataset used in this study captures information about the outcomes of energy subsidy reforms as well as their determinants. The first step in building this dataset involved collecting news articles that contain any information related to energy subsidy reform attempts through precise search queries. As described in Chapter 4, this was done by conducting a search for news articles by accessing three platforms concurrently: Nexis (2023a), ProQuest (2023), and Google (2023). This is a substantial improvement on Natalini et al. (2020) and McCulloch et al. (2022) due to their use of Google News only and its limitations for quantitative research, as pointed out in Buntain et al. (2023). Given the very high number of news articles across the three platforms, I utilized search command operators to narrow the search results, as discussed in Chapter 4. My search queries ensured that all five energy products that may be important to households – gasoline, diesel, kerosene, LPG, and electricity – were covered in the search results. As noted in Chapter 4, my final database contains over 3000 news articles, covering over 400 distinct episodes of energy subsidy reform stretching from 1995 to 2022 across 44 countries.

The 44 countries were selected based on two factors: First, a search for major episodes of energy subsidy reform was conducted without specifying the country, producing a list of countries in which major episodes occurred and were reported on in the online news databases. This list of countries included developing countries in which energy prices were subsidized and regulated by the government. This list was then compared to the list of countries in which the IEA (2023, 2024) finds consumer energy subsidies. The IEA's energy subsidy dataset includes 49 countries, but several countries (e.g., Austria and France) on their list were reported to have zero consumer energy subsidies in most years and were thus excluded from the comparison. Excluding such countries, my final list of 44 countries includes all the countries with non-zero consumer energy subsidies

listed in the IEA's (2023, 2024) energy subsidy datasets, plus additional countries in which major episodes of energy subsidy reform took place between 1995 and 2022 according to the online news databases. These additional countries are Cameroon, Côte d'Ivoire, Chad, Haiti, Jordan, Morocco, Myanmar, Namibia, Nepal, Sierra Leone, Sudan, Tunisia, and Yemen.

The 3000 news articles obtained were then reviewed manually for any content related to the absolute or percentage price increases implemented during a subsidy reform, the prices before and after the reform, the occurrence of social unrest, the occurrence of a reversal, and whether cash compensation was used to mitigate the negative impacts of reform. Quantitative data on the price changes across all five energy products were pulled into the dataset. The occurrences of unrest or a reversal were coded into two separate binary variables, with these two variables used as the dependent variables in the analysis. Finally, a binary explanatory variable was also constructed from news content reflecting whether cash compensation schemes were used to compensate households for the higher energy prices.

I also collected data on additional explanatory variables that may influence the outcomes of energy subsidy reform. These variables include those related to the type of regime in a country, people's freedoms to protest, economic performance, human development, governance, and institutional quality.

- **Political regime and civil liberties.** As noted by McCulloch et al. (2022), social unrest may be less likely to occur in countries with autocratic regimes and in countries with fewer civil liberties. The polity2 variable, obtained from the Center for Systemic Peace (CSP, 2023), reflects a country's political regime. Its values range from -10, which reflects a hereditary monarchy (e.g., Qatar and Saudi Arabia) to +10, which reflects a consolidated democracy (e.g., France and Japan). A 21-unit change therefore represents a complete transition from a hereditary monarchy to a consolidated democracy. Since the polity2 variable runs up to 2018 only, I extended the values up to 2022 for each country based on

its last data value.<sup>21</sup> As for the degree of civil freedom, I used the Civil Liberty Dataset (CLD) (Skaaning, 2020), which captures five aspects of civil freedom: 1) freedom of opinion and expression, 2) freedom of assembly and association, 3) freedom of thought, conscience and religion, 4) freedom of movement and residence, and 5) fair trial. For each of these five elements, the values range from 1 (the lowest) to 4 (the highest). I took an average of all five variables to obtain each country's average level of civil freedom. The values range from a low of 1 (e.g., Afghanistan in 2021) to a high of 4 (e.g., the United States of America in 2019). The latest CLD dataset (v2.8) currently runs up to 2023.

- **The population, level of development, and economic performance.** Explanatory variables that cover these national circumstances include population, annual GDP growth, per capita GDP (at constant prices), and inflation, all of which were obtained from the World Bank (2024a). Furthermore, I obtained from the United Nations Development Programme (UNDP, 2023) the human development index (HDI), a composite variable that captures the health (e.g., life expectancy at birth), education (e.g., mean years of schooling), and standard of living (e.g., gross national income) in a country. The HDI varies from 0 (the lowest level of human development) to 1 (the highest), but I scaled it up to vary from 0 to 100 to simplify the interpretation of the regression results.
- **Governance and institutional quality.** The World Bank (2024b) has developed the World Governance Indicators (WGIs), a dataset that captures six different dimensions of governance and institutional quality. These six variables are 1) voice and accountability, 2) political stability and the absence of violence/terrorism, 3) government effectiveness, 4) regulatory quality, 5) rule of law, and 6) control of corruption, all of which were added to the dataset. All six

---

<sup>21</sup> For most countries, the value of the polity2 variable does not change or changes very slowly over time. For example, the value for Saudi Arabia remains at -10 between 1926 and 2018. However, in rare cases, the value can change rapidly due to political upheavals. In the case of Myanmar, I extended the last value of the polity2 variable up to 2020. In 2021, the military overthrew the democratically elected government (U.S. Department of State, 2024), "undoing a decade of progress", so I set the values for 2021 and 2022 equal to the values that prevailed a decade earlier between 2011 and 2014 during the period of the military-backed government.

variables are in units of a normal standard variable with zero mean and a standard deviation of one (Kaufmann et al., 2010), so their values range from approximately -2.5 (weak governance) to +2.5 (strong governance), although the values for some countries in some years can go beyond this range.<sup>22</sup> Any missing values in this dataset during the 1995-2022 period were interpolated using the estimates for the year before and after.

- **Status as a net energy importer or exporter.** As this factor may influence citizens' expectations regarding energy subsidies (Lockwood, 2015; Chelminski, 2018), I also developed a binary variable reflecting whether a country is a net energy importer or exporter in each year. A country was classified as a net exporter of energy (coded as one) if its primary energy production was higher than its primary energy consumption, based on data from the Energy Information Administration (EIA, 2023), and classified as a net importer of energy (coded as a zero) in the opposite instance.

### 5.3.2 Dataset description

While my news articles covered over 400 distinct episodes of energy subsidy reform stretching from 1995 to 2022 across 44 countries, some episodes and countries (specifically Venezuela) had to be dropped due to the unavailability of many of the explanatory variables for those episodes or countries.

---

<sup>22</sup> The variables are defined as follows: 1) Voice and accountability captures perceptions of the extent to which a country's citizens are able to participate in selecting their government, as well as freedom of expression, freedom of association, and a free media (World Bank, 2023b); 2) political stability and the absence of violence/terrorism measures perceptions of the likelihood of political instability and/or politically-motivated violence, including terrorism (World Bank, 2023b); 3) government effectiveness captures perceptions of the quality of public services, the quality of the civil service and the degree of its independence from political pressures, the quality of policy formulation and implementation, and the credibility of the government's commitment to such policies (World Bank, 2023b); 4) regulatory quality captures perceptions of the ability of the government to formulate and implement sound policies and regulations that permit and promote private sector development (World Bank, 2023b); 5) rule of law captures perceptions of the extent to which agents have confidence in and abide by the rules of society, and in particular the quality of contract enforcement, property rights, the police, and the courts, as well as the likelihood of crime and violence (World Bank, 2023b); 6) control of corruption captures perceptions of the extent to which public power is exercised for private gain, including both petty and grand forms of corruption (World Bank, 2023b).

My final quantitative dataset contains exactly 400 episodes of energy subsidy reform, with two different dependent variables (social unrest and reform reversal) and 20 explanatory variables for each episode. The 400 episodes of energy subsidy reform can be disaggregated into 142 episodes that resulted in social unrest and 258 episodes that did not. They can also be disaggregated into 48 episodes that resulted in a reversal and 352 episodes that did not. The frequency of energy subsidy reforms implemented by country and disaggregated by outcome are shown in Table 24, which reveals extensive variation in the number of implemented reforms across countries and in outcomes. The number of reforms a country implemented depends on a multitude of factors, such as whether the country followed a gradual or an abrupt approach to reform and whether it decided to maintain fixed energy prices for long periods of time.<sup>23,24</sup> Table 24 also reveals that some countries have experienced both outcomes (e.g., Indonesia and Nigeria), while some countries have only experienced one of the outcomes (e.g., Saudi Arabia and the UAE).

---

<sup>23</sup> The number of implemented reforms in my dataset also depends on the level of news coverage that each country receives. There may have been reform episodes that were not captured in the searches of Nexis, ProQuest, and Google due to coverage-related issues. For example, news on energy subsidy reforms in some countries may have only been published in languages other than English and would thus not be captured in the news searches.

<sup>24</sup> My dataset on energy subsidy reform episodes only encompasses episodes of energy price changes in countries with subsidies (i.e., countries with regulated energy prices). Once a country fully deregulates its energy prices, any future energy price changes, which would occur in line with international market prices, would not be relevant to the analysis conducted in this paper.

**Table 24** Number of observations by outcome and country in the dataset.

| Country             | Occurrence of social unrest |            |            | Occurrence of reversal |           |            |
|---------------------|-----------------------------|------------|------------|------------------------|-----------|------------|
|                     | No = 0                      | Yes = 1    | Total      | No = 0                 | Yes = 1   | Total      |
| <i>Algeria</i>      | 1                           | 1          | 2          | 2                      | 0         | 2          |
| <i>Angola</i>       | 4                           | 0          | 4          | 4                      | 0         | 4          |
| <i>Azerbaijan</i>   | 6                           | 2          | 8          | 7                      | 1         | 8          |
| <i>Bahrain</i>      | 2                           | 0          | 2          | 2                      | 0         | 2          |
| <i>Bangladesh</i>   | 9                           | 9          | 18         | 17                     | 1         | 18         |
| <i>Bolivia</i>      | 0                           | 3          | 3          | 1                      | 2         | 3          |
| <i>Cameroon</i>     | 2                           | 3          | 5          | 4                      | 1         | 5          |
| <i>Chad</i>         | 1                           | 0          | 1          | 1                      | 0         | 1          |
| <i>Ivory Coast</i>  | 0                           | 1          | 1          | 0                      | 1         | 1          |
| <i>Ecuador</i>      | 4                           | 7          | 11         | 6                      | 5         | 11         |
| <i>Egypt</i>        | 13                          | 1          | 14         | 14                     | 0         | 14         |
| <i>El Salvador</i>  | 1                           | 0          | 1          | 1                      | 0         | 1          |
| <i>Gabon</i>        | 1                           | 0          | 1          | 1                      | 0         | 1          |
| <i>Ghana</i>        | 5                           | 5          | 10         | 9                      | 1         | 10         |
| <i>Haiti</i>        | 1                           | 5          | 6          | 5                      | 1         | 6          |
| <i>India</i>        | 7                           | 17         | 24         | 19                     | 5         | 24         |
| <i>Indonesia</i>    | 4                           | 13         | 17         | 14                     | 3         | 17         |
| <i>Iran</i>         | 12                          | 3          | 15         | 15                     | 0         | 15         |
| <i>Iraq</i>         | 6                           | 1          | 7          | 7                      | 0         | 7          |
| <i>Jordan</i>       | 11                          | 4          | 15         | 14                     | 1         | 15         |
| <i>Kazakhstan</i>   | 1                           | 1          | 2          | 1                      | 1         | 2          |
| <i>Kuwait</i>       | 4                           | 0          | 4          | 3                      | 1         | 4          |
| <i>Libya</i>        | 1                           | 0          | 1          | 1                      | 0         | 1          |
| <i>Malaysia</i>     | 17                          | 3          | 20         | 19                     | 1         | 20         |
| <i>Mexico</i>       | 2                           | 2          | 4          | 4                      | 0         | 4          |
| <i>Morocco</i>      | 3                           | 0          | 3          | 3                      | 0         | 3          |
| <i>Myanmar</i>      | 4                           | 4          | 8          | 7                      | 1         | 8          |
| <i>Namibia</i>      | 17                          | 0          | 17         | 17                     | 0         | 17         |
| <i>Nepal</i>        | 9                           | 16         | 25         | 17                     | 8         | 25         |
| <i>Nigeria</i>      | 2                           | 13         | 15         | 9                      | 6         | 15         |
| <i>Oman</i>         | 3                           | 0          | 3          | 3                      | 0         | 3          |
| <i>Pakistan</i>     | 0                           | 1          | 1          | 0                      | 1         | 1          |
| <i>Qatar</i>        | 5                           | 0          | 5          | 5                      | 0         | 5          |
| <i>Saudi Arabia</i> | 6                           | 0          | 6          | 6                      | 0         | 6          |
| <i>Sierra Leone</i> | 2                           | 3          | 5          | 4                      | 1         | 5          |
| <i>Sri Lanka</i>    | 23                          | 5          | 28         | 27                     | 1         | 28         |
| <i>Sudan</i>        | 10                          | 11         | 21         | 19                     | 2         | 21         |
| <i>Thailand</i>     | 4                           | 1          | 5          | 5                      | 0         | 5          |
| <i>Tunisia</i>      | 8                           | 2          | 10         | 10                     | 0         | 10         |
| <i>Turkmenistan</i> | 3                           | 0          | 3          | 3                      | 0         | 3          |
| <i>UAE</i>          | 10                          | 0          | 10         | 10                     | 0         | 10         |
| <i>Uzbekistan</i>   | 29                          | 0          | 29         | 29                     | 0         | 29         |
| <i>Yemen</i>        | 5                           | 5          | 10         | 7                      | 3         | 10         |
| <b>Total</b>        | <b>258</b>                  | <b>142</b> | <b>400</b> | <b>352</b>             | <b>48</b> | <b>400</b> |

Table 25 provides summary statistics on the energy price increases in my dataset, demonstrating that countries on average (across all 400 episodes) implemented increases in prices that were smaller than 30%, with increases on gasoline and diesel being higher on average than on kerosene, LPG, and electricity. Nevertheless, the range of price increases is wide, and in a few rare cases governments decreased the price of one fuel to compensate for increases in the prices of other fuels during a reform.

Table 25 also shows the mean energy price increases disaggregated by outcome. I find that – for all five energy products – the mean increases implemented in episodes that triggered social unrest were higher than the mean increases implemented in episodes that did not trigger social unrest, showing that larger price increases are correlated with unrest. The same applies to the mean increases implemented in episodes that culminated in a partial or complete reversal, as they were higher – across all five energy products – than the mean price increases implemented in episodes that were not reversed, again pointing to the possible influence of larger energy price increases on unsuccessful outcomes.

Figure 20 highlights the share of episodes and outcomes based on whether cash compensation was used. It shows that with compensation, social unrest occurred at a rate of around 30.8%. However, when compensation was not used, social unrest occurred in 36.0% of episodes. These values suggest that compensation may reduce the likelihood of unrest. In the case of reversal as an outcome, the effect of compensation is much more prominent. When compensation was used, none of the episodes resulted in a reversal (a reversal rate of 0%). In contrast, when compensation was not used, 13.4% of episodes culminated in a reversal.

Table 26 provides summary statistics for all the remaining economic, political, institutional, and governance variables, disaggregated based on whether social unrest occurred or not. It shows that social unrest is correlated to slower economic growth, lower GDP per capita, higher inflation, larger population, a lower HDI, and weaker governance across all WGI indicators, except for voice and accountability. It also shows social unrest was correlated with countries being more democratic, having more civil

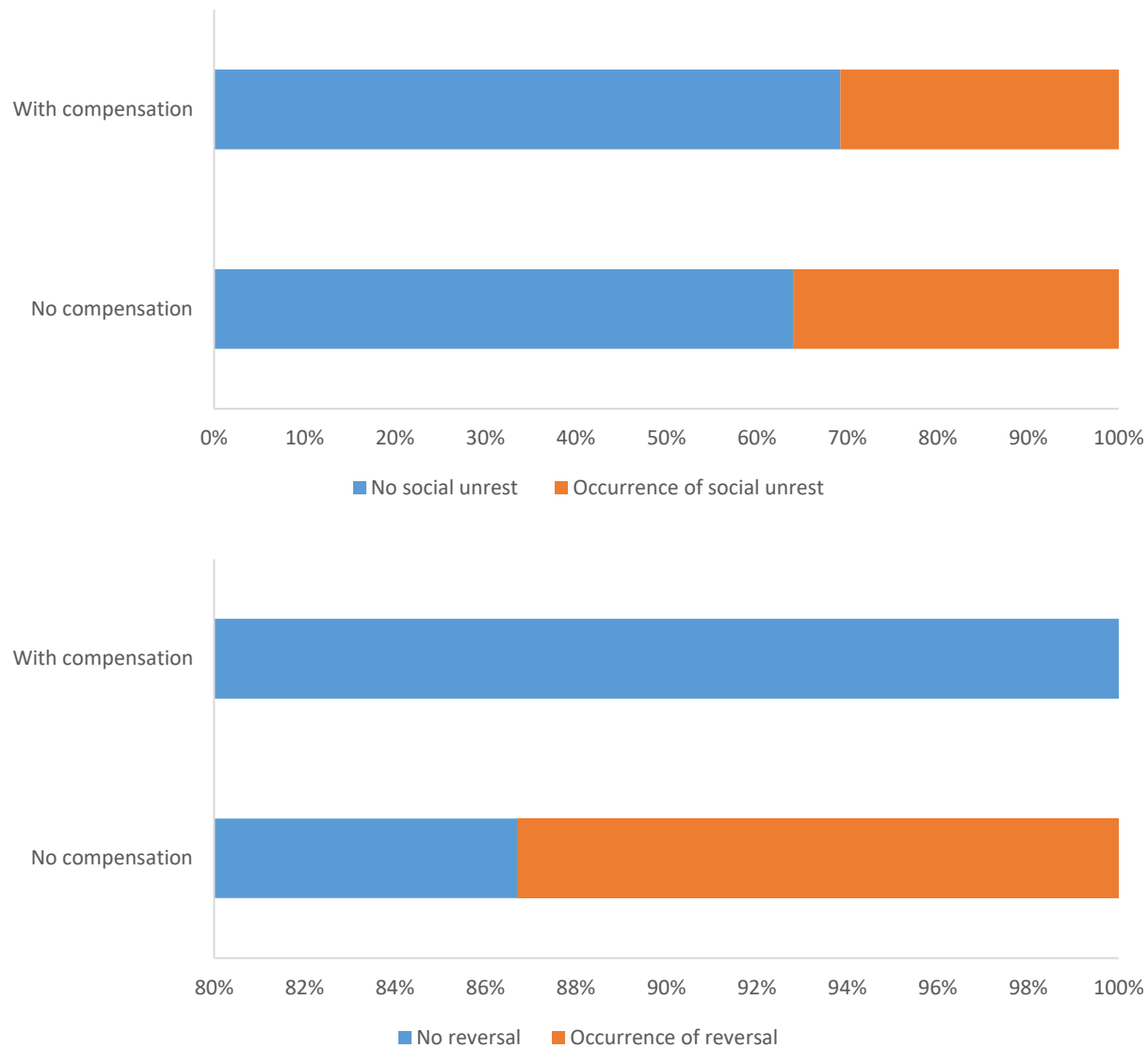
freedoms, and being importers of energy.<sup>25</sup> The exact same patterns are observed with regards to reversal as an outcome, as shown in Table 27, with only two differences: countries in which reversals occurred had on average lower levels of inflation and were more likely to be exporters of energy.

**Table 25** *Summary statistics, categorized by outcome, for the energy price increases that were implemented across all 400 episodes of energy subsidy reform.*

| Episodes                                      | Percentage increase in price of energy product (%) |          |          |          |        |             |
|-----------------------------------------------|----------------------------------------------------|----------|----------|----------|--------|-------------|
|                                               |                                                    | Gasoline | Diesel   | Kerosene | LPG    | Electricity |
| <b>No social unrest</b><br>(N=258)            | Mean                                               | 19.0%    | 21.8%    | 9.4%     | 11.7%  | 10.7%       |
|                                               | SD                                                 | 68.8%    | 103.9%   | 39.4%    | 67.5%  | 67.3%       |
|                                               | Min                                                | 0.0%     | -29.3%   | 0.0%     | 0.0%   | 0.0%        |
|                                               | Max                                                | 733.3%   | 1,415.2% | 506.1%   | 900.0% | 854.5%      |
| <b>Occurrence of social unrest</b><br>(N=142) | Mean                                               | 32.0%    | 35.2%    | 23.1%    | 14.4%  | 13.7%       |
|                                               | SD                                                 | 57.1%    | 76.1%    | 51.0%    | 40.3%  | 58.6%       |
|                                               | Min                                                | 0.0%     | 0.0%     | 0.0%     | -18.9% | 0.0%        |
|                                               | Max                                                | 525.0%   | 800.0%   | 400.0%   | 300.0% | 450.4%      |
| <b>No reversal</b><br>(N=352)                 | Mean                                               | 22.9%    | 25.2%    | 12.2%    | 11.1%  | 11.5%       |
|                                               | SD                                                 | 68.0%    | 99.5%    | 42.0%    | 59.4%  | 64.2%       |
|                                               | Min                                                | 0.0%     | 29.3%    | 0.0%     | 18.9%  | 0.0%        |
|                                               | Max                                                | 733.3%   | 1,415.2% | 506.1%   | 900.0% | 854.5%      |
| <b>Occurrence of a reversal</b><br>(N=48)     | Mean                                               | 29.0%    | 36.8%    | 29.1%    | 23.9%  | 13.7%       |
|                                               | SD                                                 | 38.2%    | 51.9%    | 56.8%    | 57.4%  | 65.4%       |
|                                               | Min                                                | 0.0%     | 0.0%     | 0.0%     | 0.0%   | 0.0%        |
|                                               | Max                                                | 183.7%   | 209.1%   | 283.3%   | 300.0% | 441.7%      |
| <b>Total</b><br>(N=400)                       | Mean                                               | 23.6%    | 26.6%    | 14.2%    | 12.7%  | 11.7%       |
|                                               | SD                                                 | 65.1%    | 95.1%    | 44.3%    | 59.2%  | 64.3%       |
|                                               | Min                                                | 0.0%     | 29.3%    | 0.0%     | 18.9%  | 0.0%        |
|                                               | Max                                                | 733.3%   | 1,415.2% | 506.1%   | 900.0% | 854.5%      |

*Note: SD = Standard deviation; Min = Minimum; Max = Maximum; N = number of episodes*

<sup>25</sup> A mean value for this binary variable that is greater than 0.5 indicates a higher percentage of exporters, while a mean value less than 0.5 indicates a lower percentage of exporters.



**Figure 20** *Energy subsidy reform outcomes disaggregated by compensation use.*

**Table 26** Summary statistics, categorized by unrest outcome, for the economic, political, institutional, and governance variables in countries across all 400 implemented episodes.

|                                  | No social unrest (N=258) |       |        |        | Occurrence of social unrest (N=142) |       |       |        | Total (N=400) |       |        |        |
|----------------------------------|--------------------------|-------|--------|--------|-------------------------------------|-------|-------|--------|---------------|-------|--------|--------|
|                                  | Mean                     | SD    | Min    | Max    | Mean                                | SD    | Min   | Max    | Mean          | SD    | Min    | Max    |
| Annual % GDP growth              | 5.2                      | 3.6   | -5.3   | 34.9   | 4.2                                 | 5.5   | -17.0 | 34.5   | 4.8           | 4.4   | -17.0  | 34.9   |
| Annual GDP per capita (2015 USD) | 7343                     | 12916 | 286    | 73493  | 2355                                | 1918  | 555   | 11291  | 5572          | 10699 | 286    | 73493  |
| Population (millions)            | 66.9                     | 191.0 | 1.4    | 1340.0 | 204.0                               | 369.0 | 6.6   | 1290.0 | 116.0         | 276.0 | 1.4    | 1340.0 |
| Government effectiveness         | -0.28                    | 0.69  | -2.09  | 1.51   | -0.65                               | 0.58  | -2.23 | 1.25   | -0.41         | 0.68  | -2.23  | 1.51   |
| Regulatory quality               | -0.49                    | 0.79  | -2.20  | 1.11   | -0.67                               | 0.51  | -2.27 | 0.54   | -0.56         | 0.71  | -2.27  | 1.11   |
| Voice and Accountability         | -0.82                    | 0.76  | -2.26  | 0.55   | -0.51                               | 0.65  | -2.21 | 0.49   | -0.71         | 0.74  | -2.26  | 0.55   |
| Political Stability              | -0.61                    | 0.92  | -2.83  | 1.20   | -1.17                               | 0.70  | -2.69 | 0.29   | -0.81         | 0.89  | -2.83  | 1.20   |
| Rule of Law                      | -0.41                    | 0.70  | -1.84  | 0.86   | -0.69                               | 0.56  | -1.74 | 0.45   | -0.51         | 0.66  | -1.84  | 0.86   |
| Control of corruption            | -0.46                    | 0.68  | -1.66  | 1.07   | -0.80                               | 0.45  | -1.63 | 0.28   | -0.58         | 0.63  | -1.66  | 1.07   |
| Regime type                      | -0.88                    | 6.44  | -10.00 | 9.00   | 3.37                                | 5.24  | -8.00 | 9.00   | 0.63          | 6.37  | -10.00 | 9.00   |
| Civil Freedom                    | 2.23                     | 0.61  | 1.20   | 3.60   | 2.57                                | 0.50  | 1.40  | 3.60   | 2.35          | 0.60  | 1.20   | 3.60   |
| Human Development Index          | 0.66                     | 0.11  | 0.37   | 0.88   | 0.58                                | 0.10  | 0.38  | 0.80   | 0.63          | 0.12  | 0.37   | 0.88   |
| Annual % inflation               | 15.8                     | 42.4  | -16.1  | 359.1  | 20.4                                | 46.7  | -0.2  | 359.1  | 17.4          | 44.0  | -16.1  | 359.1  |
| Exporter or importer             | 0.55                     | 0.50  | 0.00   | 1.00   | 0.47                                | 0.50  | 0.00  | 1.00   | 0.53          | 0.50  | 0.00   | 1.00   |

Notes: SD = Standard deviation; Min = Minimum; Max = Maximum; N = number of episodes

**Table 27** Summary statistics, categorized by reversal outcome, for the economic, political, institutional, and governance variables in countries across all 400 implemented episodes.

|                                  | No reversal (N=352) |         |        |         | Occurrence of reversal (N=48) |        |       |         | Total (N=400) |         |        |         |
|----------------------------------|---------------------|---------|--------|---------|-------------------------------|--------|-------|---------|---------------|---------|--------|---------|
|                                  | Mean                | SD      | Min    | Max     | Mean                          | SD     | Min   | Max     | Mean          | SD      | Min    | Max     |
| Annual % GDP growth              | 5.0                 | 4.4     | -17.0  | 34.9    | 4.0                           | 3.8    | -13.1 | 14.0    | 4.8           | 4.4     | -17.0  | 34.9    |
| Annual GDP per capita (2015 USD) | 5939.2              | 11243.7 | 286.0  | 73493.3 | 2879.4                        | 4378.3 | 554.5 | 29315.2 | 5572.0        | 10698.7 | 286.0  | 73493.3 |
| Population (millions)            | 108.0               | 265.0   | 1.4    | 1340.0  | 171.0                         | 343.0  | 3.9   | 1270.0  | 116.0         | 276.0   | 1.4    | 1340.0  |
| Government effectiveness         | -0.37               | 0.69    | -2.23  | 1.51    | -0.66                         | 0.51   | -1.93 | 0.99    | -0.41         | 0.68    | -2.23  | 1.51    |
| Regulatory quality               | -0.55               | 0.74    | -2.27  | 1.11    | -0.62                         | 0.43   | -1.50 | 0.54    | -0.56         | 0.71    | -2.27  | 1.11    |
| Voice and Accountability         | -0.73               | 0.75    | -2.26  | 0.55    | -0.56                         | 0.60   | -1.86 | 0.48    | -0.71         | 0.74    | -2.26  | 0.55    |
| Political Stability              | -0.76               | 0.89    | -2.83  | 1.20    | -1.17                         | 0.75   | -2.68 | 0.17    | -0.81         | 0.89    | -2.83  | 1.20    |
| Rule of Law                      | -0.48               | 0.68    | -1.84  | 0.86    | -0.72                         | 0.53   | -1.71 | 0.35    | -0.51         | 0.66    | -1.84  | 0.86    |
| Control of corruption            | -0.56               | 0.65    | -1.66  | 1.07    | -0.79                         | 0.40   | -1.57 | 0.28    | -0.58         | 0.63    | -1.66  | 1.07    |
| Regime type                      | 0.36                | 6.43    | -10.00 | 9.00    | 2.58                          | 5.53   | -7.00 | 9.00    | 0.63          | 6.37    | -10.00 | 9.00    |
| Civil Freedom                    | 2.32                | 0.60    | 1.20   | 3.60    | 2.56                          | 0.52   | 1.40  | 3.60    | 2.35          | 0.60    | 1.20   | 3.60    |
| Human Development Index          | 0.64                | 0.12    | 0.37   | 0.88    | 0.57                          | 0.12   | 0.38  | 0.83    | 0.63          | 0.12    | 0.37   | 0.88    |
| Annual % inflation               | 17.4                | 45.6    | -16.1  | 359.1   | 17.8                          | 29.4   | 0.3   | 132.8   | 17.4          | 44.0    | -16.1  | 359.1   |
| Exporter or importer             | 0.52                | 0.50    | 0.00   | 1.00    | 0.56                          | 0.50   | 0.00  | 1.00    | 0.53          | 0.50    | 0.00   | 1.00    |

Notes: SD = Standard deviation; Min = Minimum; Max = Maximum; N = number of episodes

### 5.3.3 Logistic regression methods

#### 5.3.3.1 Pooled logistic regression

As both my outcome variables are binary, I run logistic regressions to quantify how each explanatory variable influences the occurrence of social unrest (the first outcome and dependent variable) and the reversal of the reform (the second outcome and dependent variable). In my pooled dataset, the unit of analysis is an episode of energy subsidy reform, denoted by the subscript  $i$ . In other words, each episode  $i$  is treated as an observation.

The first general logit model that I estimate is:

$$\begin{aligned} \text{logit}(\text{social unrest}_i) = & \alpha_0 + \alpha_1 \text{GAS}_i + \alpha_2 \text{DSL}_i + \alpha_3 \text{LPG}_i + \alpha_4 \text{KER}_i + \\ & \alpha_5 \text{ELC}_i + \alpha_6 \text{COMP}_i + \alpha_7 \ln(\text{POP}_i) + \alpha_8 \text{GDPG}_i + \alpha_9 \ln(\text{GDPPC}_i) + \alpha_{10} \text{GE}_i + \\ & \alpha_{11} \text{RQ}_i + \alpha_{12} \text{VA}_i + \alpha_{13} \text{PSNV}_i + \alpha_{14} \text{RL}_i + \alpha_{15} \text{CC}_i + \alpha_{16} \text{RT}_i + \alpha_{17} \text{CF}_i + \alpha_{18} \text{HDI}_i + \\ & \alpha_{19} \text{INF}_i + \alpha_{20} \text{XM}_i + \varepsilon_i \end{aligned} \quad [31]$$

where  $\text{social unrest}_i$  captures whether social unrest occurs following an episode  $i$  of energy subsidy reform. The explanatory variables are defined as follows:

- $\text{GAS}_i$  is the percentage increase in the gasoline price during episode  $i$ ;
- $\text{DSL}_i$  is the percentage increase in the diesel price during episode  $i$ ;
- $\text{LPG}_i$  is the percentage increase in the LPG price during episode  $i$ ;
- $\text{KER}_i$  is the percentage increase in the kerosene price during episode  $i$ ;
- $\text{ELC}_i$  is the percentage increase in the residential electricity price during episode  $i$ ;
- $\text{COMP}_i$  reflects whether a cash compensation scheme was launched alongside episode  $i$ ;
- $\text{POP}_i$  is the annual population in the country when it implemented episode  $i$ ;
- $\text{GDPG}_i$  is the annual GDP percentage growth for the country when it implemented episode  $i$ ;
- $\text{GDPPC}_i$  is the annual GDP per capita for the country when it implemented episode  $i$ ;
- $\text{GE}_i$  is the annual level of government effectiveness when it implemented episode  $i$ ;

- $RQ_i$  is the annual level of regulatory quality in the country when it implemented episode  $i$ ;
- $VA_i$  is the annual level of voice and accountability in the country when it implemented episode  $i$ ;
- $PS_i$  is the annual level of political stability in the country when it implemented episode  $i$ ;
- $RL_i$  is the annual level of rule of law in the country when it implemented episode  $i$ ;
- $CC_i$  is the annual level of corruption control in the country when it implemented episode  $i$ ;
- $RT_i$  reflects the annual regime type (i.e., democracy level) in the country when it implemented episode  $i$ ;
- $HDI_i$  is the annual human development index in the country when it implemented episode  $i$ ;
- $INF_i$  reflects the annual percentage of inflation in the country when it implemented episode  $i$ ;
- $XM_i$  captures whether the country was a net exporter or importer of energy in the year when it implemented episode  $i$ ; and
- $\varepsilon_i$  represents the random error term.

The second general logit model that I estimate is:

$$\begin{aligned} \text{logit}(\text{reversal}_i) = & \beta_0 + \beta_1 \text{GAS}_i + \beta_2 \text{DSL}_i + \beta_3 \text{LPG}_i + \beta_4 \text{KER}_i + \beta_5 \text{ELC}_i + \beta_6 \text{COMP}_i + \\ & \alpha_7 \ln(\text{POP}_i) + \beta_8 \text{GDPG}_i + \beta_9 \ln(\text{GDPPC}_i) + \beta_{10} \text{GE}_i + \beta_{11} \text{RQ}_i + \beta_{12} \text{VA}_i + \beta_{13} \text{PSNV}_i + \\ & \beta_{14} \text{RL}_i + \beta_{15} \text{CC}_i + \beta_{16} \text{RT}_i + \beta_{17} \text{CF}_i + \beta_{18} \text{HDI}_i + \beta_{19} \text{INF}_i + \beta_{20} \text{XM}_i + \varepsilon_i \end{aligned} \quad [32]$$

where  $\text{reversal}_i$  captures whether an episode  $i$  of energy subsidy reform is reversed or not.

The  $\alpha$  and  $\beta$  coefficients in Equation [31] and Equation [32] reflect the ceteris paribus effects of each explanatory variable on the occurrence of social unrest and reversal, respectively, with  $\alpha_0$  and  $\beta_0$  being the intercept terms.

In statistical model building, the general-to-specific approach is conventionally used to find “the most parsimonious model that still accurately reflects the true outcome

experience of the data” (Hosmer et al., 2013). Hosmer et al. (2013) noted the rationale for minimizing the number of variables in a model to produce a model that is 1) more numerically stable, 2) more easily adopted for use, and 3) less likely to suffer from overfitting. Using the general-to-specific approach, I tested down to produce parsimonious models by dropping variables that were not statistically significant or problematic variables that were causing multicollinearity issues while monitoring an array of goodness-of-fit measures and diagnostic tests, including the likelihood ratio (LR) chi-square test, the pseudo R-squared, specification error tests, multicollinearity tests, and information criteria. A 10% level of statistical significance was used to determine whether any coefficient or test outcome was statistically significant. Throughout this chapter, the superscripts \*, \*\*, and \*\*\* are used to represent significance at the 10%, 5%, and 1% levels.

While starting from the most general model is one approach, Hosmer et al. (2013) recommend a method that they refer to as “purposeful selection”. Purposeful selection begins with a univariable analysis of each explanatory variable in the general model, where a univariable logistic regression is fitted for each explanatory variable. Any explanatory variables that have a p-value higher than 0.25 in the univariable regressions are then eliminated. Purposeful selection thus produces a model that is nested by the general model, assuming at least one explanatory variable gets eliminated in the screening step. Hosmer et al. (2013) then recommend testing down from the purposeful selection model following the standard general-to-specific approach described above.

Applying the purposeful selection method described by Hosmer et al. (2013) to Equation [31], the variables  $LPG_i$ ,  $ELC_i$ ,  $COMP_i$ , and  $INF_i$  fail the screening test, leading to the following model for social unrest as a dependent variable:

$$\begin{aligned} \text{logit}(\text{social unrest}_i) = & \alpha_0 + \alpha_1 GAS_i + \alpha_2 DSL_i + \alpha_4 KER_i + \alpha_7 \ln(POP_i) + \alpha_8 GDPG_i + \\ & \alpha_9 \ln(GDPPC_i) + \alpha_{10} GE_i + \alpha_{11} RQ_i + \alpha_{12} VA_i + \alpha_{13} PSNV_i + \alpha_{14} RL_i + \alpha_{15} CC_i + \alpha_{16} RT_i + \\ & \alpha_{17} CF_i + \alpha_{18} HDI_i + \alpha_{20} XM_i + \varepsilon_i \end{aligned} \quad [33]$$

Similarly, after applying purposeful selection to Equation [32], the variables  $GAS_i$ ,  $DSL_i$ ,  $ELC_i$ ,  $RQ_i$ ,  $INF_i$ , and  $XM_i$  fail the screening test. Furthermore,  $COMP_i$  is found to

perfectly predict the occurrence of a reversal, as shown in Figure 20, so the variable had to be omitted from the general model. Purposeful selection led to the following model for reversal as a dependent variable:

$$\begin{aligned} \text{logit}(\text{reversal}_i) = & \beta_0 + \beta_3 \text{LPG}_i + \beta_4 \text{KER}_i + \alpha_7 \ln(\text{POP}_i) + \beta_8 \text{GDPG}_i + \\ & \beta_9 \ln(\text{GDPPC}_i) + \beta_{10} \text{GE}_i + \beta_{12} \text{VA}_i + \beta_{13} \text{PSNV}_i + \beta_{14} \text{RL}_i + \beta_{15} \text{CC}_i + \beta_{16} \text{RT}_i + \\ & \beta_{17} \text{CF}_i + \beta_{18} \text{HDI}_i + \varepsilon_i \end{aligned} \quad [34]$$

The *logit* command in Stata 16.0 (StataCorp, 2019) was used to run the pooled logistic regression estimations.

I also included different sets of dummy variables in the models. First, I tested time dummies, including month-year and year time dummies. Month-year time dummies proved to be problematic given the small number of energy subsidy reform episodes implemented during a month-year, which often shared the same outcome, leading to most observations being dropped from the regressions as the month-year dummies perfectly predicted the outcomes. Therefore, I did not consider month-year time dummies any further. I then tested year time dummies. The inclusion of year time dummies led to the loss of only several observations, so I proceeded to estimate and compare models with year time dummies. I also tested country dummies. Country dummies also proved to be problematic, but not as problematic as month-year time dummies. Many countries in my dataset experienced only one outcome when attempting energy subsidy reforms. In other words, these countries showed no variation in the dependent variable. For social unrest as a dependent variable, 18 of the 43 countries in my dataset implemented energy subsidy reforms that produced only one outcome. Since the dummies for these countries perfectly predict the outcome, all the episodes implemented by these 18 countries get omitted from the regression. In the case of reversal as a dependent variable, 23 of the 43 countries in my dataset implemented reforms with no variation in the reversal outcome. Since the dummies for these countries also perfectly predict the outcome, all the episodes implemented by these 23 countries get omitted from the regression. Therefore, the inclusion of country dummies leads to a significantly less-powered regression, which is a substantial cost

given the relatively small dataset size, but I continued to estimate and compare models with country dummies.

### 5.3.3.2 Panel logistic regression

My regression analysis could also be conducted by treating the dataset as a panel. Since some countries in my dataset implemented multiple episodes of energy subsidy reform in the same year, I set month-year as the time variable and country as the panel variable. This produced a very unbalanced panel in which only a few countries implemented any energy subsidy reforms in each month-year of the study period. My 28-year study period (1995-2022) includes a total of 336 month-years, and reforms were implemented in 211 of these month-years, with no reforms implemented in the remaining 125 month-years. Furthermore, the average number of energy subsidy reforms implemented by any country in each month-year (across the 211) was only 1.9 episodes. Nevertheless, I proceeded with running panel regressions, and the panel versions of Equation [31] and Equation [32], which include the unobserved effects for countries (Wooldridge, 2010), are respectively shown below:

$$\begin{aligned} \text{logit}(\text{social unrest}_{jt}) = & \alpha_0 + \alpha_1 \text{GAS}_{jt} + \alpha_2 \text{DSL}_{jt} + \alpha_3 \text{LPG}_{jt} + \alpha_4 \text{KER}_{jt} + \alpha_5 \text{ELC}_{jt} + \\ & \alpha_6 \text{COMP}_{jt} + \alpha_7 \ln(\text{POP}_{jt}) + \alpha_8 \text{GDPG}_{jt} + \alpha_9 \ln(\text{GDPPC}_{jt}) + \alpha_{10} \text{GE}_{jt} + \alpha_{11} \text{RQ}_{jt} + \alpha_{12} \text{VA}_{jt} + \\ & \alpha_{13} \text{PSNV}_{jt} + \alpha_{14} \text{RL}_{jt} + \alpha_{15} \text{CC}_{jt} + \alpha_{16} \text{RT}_{jt} + \alpha_{17} \text{CF}_{jt} + \alpha_{18} \text{HDI}_{jt} + \alpha_{19} \text{INF}_{jt} + \alpha_{20} \text{XM}_{jt} + \\ & c_j + \varepsilon_{jt} \end{aligned} \quad [35]$$

$$\begin{aligned} \text{logit}(\text{reversal}_{jt}) = & \beta_0 + \beta_1 \text{GAS}_{jt} + \beta_2 \text{DSL}_{jt} + \beta_3 \text{LPG}_{jt} + \beta_4 \text{KER}_{jt} + \beta_5 \text{ELC}_{jt} + \\ & \beta_6 \text{COMP}_{jt} + \beta_7 \ln(\text{POP}_{jt}) + \beta_8 \text{GDPG}_{jt} + \beta_9 \ln(\text{GDPPC}_{jt}) + \beta_{10} \text{GE}_{jt} + \beta_{11} \text{RQ}_{jt} + \beta_{12} \text{VA}_{jt} + \\ & \beta_{13} \text{PSNV}_{jt} + \beta_{14} \text{RL}_{jt} + \beta_{15} \text{CC}_{jt} + \beta_{16} \text{RT}_{jt} + \beta_{17} \text{CF}_{jt} + \beta_{18} \text{HDI}_{jt} + \beta_{19} \text{INF}_{jt} + \beta_{20} \text{XM}_{jt} + c_j + \\ & \varepsilon_{jt} \end{aligned} \quad [36]$$

The subscript  $j$  denotes the country, in contrast to the subscript  $i$  used previously to denote episodes of energy subsidy reform. The subscript  $t$  denotes the time interval, which is month-year. The unobserved effects (or unobserved heterogeneity) are denoted by  $c_j$ . The random effects and fixed effects estimators were both used, which I ran using the *xtlogit* command in Stata 16.0 (StataCorp, 2019).

## 5.4 Logistic Regression Results

### 5.4.1 Results for social unrest as the dependent variable

#### 5.4.1.1 *Selecting a final model for social unrest*

The logistic regression results for the general model are shown in Table 28, starting with the pooled general model with no dummy variables, given by Equation [31]. I then tested the inclusion of year dummies, finding none to be statistically significant but the set of them to be jointly significant. I then tested the inclusion of country dummies, and ran into the previously discussed issue, where half of the countries were dropped due to their dummies perfectly predicting the outcome. With only half the countries remaining, I found that the country dummies were jointly significant. I also tested the inclusion of both sets of dummies. With half the countries being dropped again, the country dummies were found to be jointly significant, while the time dummies were not. While the p-values suggest that country dummies should be included, doing so comes at the cost of losing half of all countries and a quarter of all observations – a substantial cost given the relatively small sample size. Additionally, all the general models in Table 28 suffered from severe multicollinearity, with five explanatory variables exhibiting variance inflation factors (VIFs) greater than ten. Furthermore, some of the large estimated coefficients indicate the possibility of overfitting issues (Hosmer et al., 2013).

I also estimated panel data models. I found that the panel-level variance component, denoted by  $\rho$ , was zero. The LR test of whether  $\rho$  equals zero was used to compare the pooled estimator to the panel estimator for the general model. The LR test produced a p-value of 0.262, failing to reject the null hypothesis that  $\rho$  equals zero. This test result suggests continuing to use the pooled estimator in the regression analysis.

Having established that the pooled estimator is preferred and that there may be overfitting issues with the general model, I proceeded to estimate Equation [33], which was obtained by purposeful selection. The results are shown in Table 29 with different sets of dummy variables, starting with the purposeful selection model with no dummies. I then tested the inclusion of year time dummies, finding them to be jointly significant. I then tested the inclusion of country dummies and ran into the previously discussed

issue of half the countries being dropped but found the country dummies to be significant. I also tested the inclusion of time and country dummies, finding that doing so led to each set of dummies no longer being jointly significant. Unlike the general model, the purposeful selection model results suggest that all dummies can be dropped from the regressions. However, the purposeful selection model, despite including fewer explanatory variables than the general model, continued to suffer from severe multicollinearity, with several variables exhibiting VIF values greater than ten.

I subsequently tested down from the purposeful selection model, following the general-to-specific approach, to look for a more parsimonious model. Through this procedure, three models were obtained, which are shown in Table 30. Model 1 includes eight statistically significant explanatory variables alongside the constant. Model 2 resembles model 1 but excludes political stability as an explanatory variable, due to possible endogeneity issues (Natalini et al., 2020). Unlike models 1 and 2, model 3 excludes the population but instead includes GDP per capita as a statistically significant explanatory variable. All explanatory variables across all three models were significant at the 10% level, with only the gasoline price increase in model 3 having a borderline p-value of 0.101. All three parsimonious models did not have any multicollinearity issues, in contrast to the general and purposeful selection models.

I compared the general, purposeful selection, and three parsimonious models presented in Table 28 through Table 30 using various goodness-of-fit statistics. According to Akaike's Information Criterion (AIC), the superior model is the purposeful selection model that includes country and time dummies, which had the lowest AIC of 352.9. However, excluding models with country dummies, which led to a significant loss in the number of observations, model 1 emerges as the superior model with an AIC of 415.1, followed closely by model 2 with an AIC of 417.1. However, when using the Bayesian Information Criterion (BIC), model 2 emerges as the superior model, with the lowest BIC of 449.0 among all models, including the ones with country dummies.

Proceeding with parsimonious model 2 for further analysis, I tested for time and country dummies. Time dummies were not jointly significant, but country dummies were.

Including country and time dummies together revealed both sets to be jointly significant, but this again comes with the loss of many observations.

I also estimated model 2 using fixed effects and random effects panel estimators. Table 31 demonstrates that the results obtained using the pooled estimator and the random effects panel estimator are very similar. However, differences were observed in the results obtained with the fixed effects panel estimator, which caused the variables for annual GDP growth, population, and human development to no longer be statistically significant, while increasing the statistical significance of all the price increase variables. Furthermore, the use of fixed effects (i.e., country dummies) led to the same loss of observations discussed previously. Using the Hausman test to compare fixed and random effects, I found that the random effects estimator was preferred over fixed effects. As noted by Wooldridge (2010), in cases where the explanatory variables do not vary much over time, as is the case here for many of the variables like civil freedom, fixed effects estimators can lead to imprecise estimates. The analysis leads to a choice between the pooled and random effects estimators. I proceeded with the pooled estimator since it is 1) consistent even when strict exogeneity does not hold (Söderbom et al., 2015), 2) was used throughout the general-to-specific testing down procedure, and 3) produces very similar results to random effects. To summarize, I proceeded with model 2 (using the pooled estimator) as the final model.

I then conducted further tests on the final social unrest model. Table 32 shows its sensitivity and specificity, two classification statistics that reflect the shares of actual positives (i.e., the occurrence of social unrest) and actual negatives (i.e., no social unrest) that are correctly identified by the final model. The rate of correctly identifying the occurrence of social unrest is 57.0%, while the rate of correctly identifying the absence of social unrest is 84.9%. The superior classification results for detecting the absence of social unrest stem from its larger group size, as there were 142 episodes that led to social unrest and 258 episodes that did not. When the distribution of outcomes is unbalanced, studies have shown that the default approach of using a cut-off probability of 0.5 for assigning a successful or unsuccessful outcome does not work well (e.g., Freeman and Moisen, 2008). Hosmer et al. (2013) recommended choosing a

cut-off point where the sensitivity and specificity curves approximately cross (i.e., have similar values). By changing the cut-off to 0.378, the rate of correctly identifying the occurrence of unrest rises from 57.0% to 75.4%, at the cost of a smaller deterioration in the rate of correctly identifying the absence of unrest from 84.9% to 75.2%. Finally, I measured the area under the receiver operating characteristic (ROC) curve, which plots the sensitivity against one minus the specificity for a range of cut-off values. I measured the area under the ROC curve to be 0.82, indicating a final social unrest model that is strong at predicting outcomes correctly (Hosmer et al., 2013).

**Table 28** Estimated general models (using pooled estimator) and goodness-of-fit tests with different sets of dummy variables.

| <b>Dependent variable:<br/>social unrest</b>     | <b>General model<br/>(no dummies)</b> | <b>General model<br/>(+ time dummies)</b> | <b>General model<br/>(+ country dummies)</b> | <b>General model<br/>(+ country &amp; time<br/>dummies)</b> |
|--------------------------------------------------|---------------------------------------|-------------------------------------------|----------------------------------------------|-------------------------------------------------------------|
| <i>Gasoline price % increase (GAS)</i>           | 0.00786**                             | 0.00920**                                 | 0.02488***                                   | 0.030165***                                                 |
| <i>Diesel price % increase (DSL)</i>             | -0.00523**                            | -0.00582**                                | -0.01989***                                  | -0.02552***                                                 |
| <i>LPG price % increase (LPG)</i>                | -0.00502*                             | -0.00447                                  | -0.00112                                     | 0.004562                                                    |
| <i>Kerosene price % increase<br/>(KER)</i>       | 0.01566***                            | 0.02217***                                | 0.04345***                                   | 0.064434***                                                 |
| <i>Electricity price % increase<br/>(ELC)</i>    | 0.00161                               | 0.00103                                   | 0.00168                                      | 0.00086                                                     |
| <i>Compensation (COMP)</i>                       | 0.42942                               | -0.71077                                  | -0.29184                                     | -2.09867**                                                  |
| <i>Annual % GDP growth (GDPG)</i>                | -0.07430**                            | -0.04545                                  | -0.04589                                     | 0.014797                                                    |
| <i>Log annual GDP per capita<br/>(GDPPC)</i>     | -0.26213                              | -0.59165                                  | 9.1785***                                    | 6.729288*                                                   |
| <i>Log population (POP)</i>                      | 0.41800***                            | 0.21554                                   | 8.60380***                                   | -10.0498                                                    |
| <i>Government effectiveness (GE)</i>             | -0.75053                              | 0.89214                                   | -1.66506                                     | -1.29672                                                    |
| <i>Regulatory quality (RQ)</i>                   | 0.88861                               | 1.16300*                                  | 0.16635                                      | 3.303677*                                                   |
| <i>Voice and Accountability (VA)</i>             | -0.58678                              | -0.06993                                  | -0.79828                                     | -1.15556                                                    |
| <i>Political Stability (PS)</i>                  | -0.06997                              | -0.64974*                                 | 0.65252                                      | 0.155384                                                    |
| <i>Rule of Law (RL)</i>                          | -0.43563                              | -0.80948                                  | 0.82590                                      | 0.417901                                                    |
| <i>Control of corruption (CC)</i>                | -0.10665                              | -0.60761                                  | -1.97255                                     | -5.1005***                                                  |
| <i>Regime type (RT)</i>                          | 0.06086                               | 0.09234                                   | -0.01839                                     | 0.061839                                                    |
| <i>Civil Freedom (CF)</i>                        | 1.33472*                              | 1.05250                                   | 3.64974***                                   | 4.307967**                                                  |
| <i>Human Development Index (HDI)</i>             | -0.01886                              | -0.05462*                                 | -0.52560***                                  | -1.11304***                                                 |
| <i>Annual % inflation (INF)</i>                  | -0.00028                              | 0.00465                                   | -0.00173                                     | 0.008189                                                    |
| <i>Exporter or importer (XM)</i>                 | 0.45559                               | 1.28739***                                | -1.26680                                     | -0.07916                                                    |
| <i>Constant</i>                                  | -8.72508*                             | 0.07923                                   | -196.16510***                                | 180.6621                                                    |
| <i>likelihood ratio (LR) chi-square<br/>test</i> | chi2(20) = 140.08***                  | chi2(46) = 189.28***                      | chi2(44) = 144.06***                         | chi2(70) = 202.89***                                        |
| <i>Pseudo R-squared</i>                          | 0.2692                                | 0.3656                                    | 0.3433                                       | 0.4876                                                      |
| <i>AIC</i>                                       | 422.3                                 | 422.5                                     | 365.6                                        | 419.66                                                      |
| <i>BIC</i>                                       | 506.1                                 | 609.7                                     | 533.0                                        | 503.06                                                      |

**Table 29** Estimated purposeful selection models (using pooled estimator) and goodness-of-fit tests with different sets of dummies.

| <i>Dependent variable:<br/>social unrest</i>     | <i>Purposeful selection<br/>model (no dummies)</i> | <i>Purposeful selection<br/>model<br/>(+ time dummies)</i> | <i>Purposeful selection<br/>model<br/>(+ country dummies)</i> | <i>Purposeful selection<br/>model<br/>(+ country &amp; time<br/>dummies)</i> |
|--------------------------------------------------|----------------------------------------------------|------------------------------------------------------------|---------------------------------------------------------------|------------------------------------------------------------------------------|
| <i>Gasoline price % increase (GAS)</i>           | 0.004558                                           | 0.005553*                                                  | 0.023625***                                                   | 0.028154***                                                                  |
| <i>Diesel price % increase (DSL)</i>             | -0.00386                                           | -0.00415                                                   | -0.01932***                                                   | -0.02338***                                                                  |
| <i>LPG price % increase (LPG)</i>                |                                                    |                                                            |                                                               |                                                                              |
| <i>Kerosene price % increase<br/>(KER)</i>       | 0.011567**                                         | 0.015787***                                                | 0.041737***                                                   | 0.05858***                                                                   |
| <i>Electricity price % increase<br/>(ELC)</i>    |                                                    |                                                            |                                                               |                                                                              |
| <i>Compensation (COMP)</i>                       |                                                    |                                                            |                                                               |                                                                              |
| <i>Annual % GDP growth (GDPG)</i>                | -0.07696**                                         | -0.04572                                                   | -0.0436                                                       | 0.010954                                                                     |
| <i>Log annual GDP per capita<br/>(GDPPC)</i>     | -0.23871                                           | -0.48642                                                   | 9.378156***                                                   | 7.384314**                                                                   |
| <i>Log population (POP)</i>                      | 0.431222***                                        | 0.249831                                                   | 8.522376***                                                   | -7.77576                                                                     |
| <i>Government effectiveness (GE)</i>             | -0.78183                                           | 0.713868                                                   | -1.7099                                                       | -1.66092                                                                     |
| <i>Regulatory quality (RQ)</i>                   | 0.856772                                           | 1.11737*                                                   | 0.16724                                                       | 2.821102                                                                     |
| <i>Voice and Accountability (VA)</i>             | -0.5233                                            | -0.1056                                                    | -0.84084                                                      | -0.8951                                                                      |
| <i>Political Stability (PS)</i>                  | -0.01838                                           | -0.55862*                                                  | 0.649131                                                      | 0.287619                                                                     |
| <i>Rule of Law (RL)</i>                          | -0.4933                                            | -0.8846                                                    | 0.733595                                                      | 0.658714                                                                     |
| <i>Control of corruption (CC)</i>                | -0.02594                                           | -0.55345                                                   | -2.00713                                                      | -4.83821*                                                                    |
| <i>Regime type (RT)</i>                          | 0.063412                                           | 0.085928                                                   | -0.02245                                                      | 0.024307                                                                     |
| <i>Civil Freedom (CF)</i>                        | 1.120961                                           | 1.026742                                                   | 3.726872***                                                   | 4.109005**                                                                   |
| <i>Human Development Index (HDI)</i>             | -0.02031                                           | -0.06286**                                                 | -0.53795***                                                   | -1.00222***                                                                  |
| <i>Annual % inflation (INF)</i>                  |                                                    |                                                            |                                                               |                                                                              |
| <i>Exporter or importer (XM)</i>                 | 0.378288                                           | 1.079974**                                                 | -1.21084                                                      | -0.66305                                                                     |
| <i>Constant</i>                                  | -8.32662*                                          | -0.09631                                                   | -196.027***                                                   | 130.8016                                                                     |
| <i>likelihood ratio (LR) chi-square<br/>test</i> | chi2(16) = 134.9***                                | chi2(42) = 184.6***                                        | chi2(40) = 142.8***                                           | chi2(66) = 197.1***                                                          |
| <i>Pseudo R-squared</i>                          | 0.2593                                             | 0.3566                                                     | 0.3404                                                        | 0.4738                                                                       |
| <i>AIC</i>                                       | 419.5                                              | 419.1                                                      | 358.8                                                         | 352.9                                                                        |
| <i>BIC</i>                                       | 487.3                                              | 590.4                                                      | 511.4                                                         | 601.5                                                                        |

**Table 30** Estimated parsimonious models (using pooled estimator) and goodness-of-fit tests. Note: BL = borderline statistically significant.

| <b>Dependent variable:<br/>social unrest</b> | <b>Model 1<br/>(no dummies)</b> | <b>Model 2<br/>(no dummies)</b> | <b>Model 3<br/>(no dummies)</b> |
|----------------------------------------------|---------------------------------|---------------------------------|---------------------------------|
| Gasoline price % increase (GAS)              | 0.006144*                       | 0.005725*                       | 0.005700 <sup>BL</sup>          |
| Diesel price % increase (DSL)                | -0.00479*                       | -0.00471*                       | -0.004505*                      |
| LPG price % increase (LPG)                   |                                 |                                 |                                 |
| Kerosene price % increase (KER)              | 0.01198***                      | 0.01253***                      | 0.012250***                     |
| Electricity price % increase (ELC)           |                                 |                                 |                                 |
| Compensation (COMP)                          |                                 |                                 |                                 |
| Annual % GDP growth (GDPG)                   | -0.08192**                      | -0.09489**                      | -0.09338***                     |
| Log annual GDP per capita (GDPPC)            |                                 |                                 | -0.59564***                     |
| Log population (POP)                         | 0.33289***                      | 0.42833***                      |                                 |
| Government effectiveness (GE)                |                                 |                                 |                                 |
| Regulatory quality (RQ)                      |                                 |                                 |                                 |
| Voice and Accountability (VA)                |                                 |                                 |                                 |
| Political Stability (PS)                     | -0.39165**                      |                                 |                                 |
| Rule of Law (RL)                             |                                 |                                 |                                 |
| Control of corruption (CC)                   |                                 |                                 |                                 |
| Regime type (RT)                             |                                 |                                 |                                 |
| Civil Freedom (CF)                           | 1.18197***                      | 0.98764 ***                     | 0.88609***                      |
| Human Development Index (HDI)                | -0.04538***                     | -0.05647***                     | -0.03274**                      |
| Annual % inflation (INF)                     |                                 |                                 |                                 |
| Exporter or importer (XM)                    |                                 |                                 |                                 |
| Constant                                     | -6.62457***                     | -6.69125***                     | 4.17227***                      |
| likelihood ratio (LR) chi-square test        | chi2(8) = 123.3***              | chi2(7) = 119.32***             | chi2(7) = 99.37***              |
| Pseudo R-squared                             | 0.2369                          | 0.2293                          | 0.1910                          |
| AIC                                          | 415.1                           | 417.1                           | 437.0                           |
| BIC                                          | 451.0                           | 449.0                           | 469.0                           |

**Table 31** Final model 2 logistic regression results using different estimators.

| <b>Dependent variable:<br/>social unrest</b> | <b>Model 2<br/>(pooled estimator)</b> | <b>Model 2<br/>(random effects)</b> | <b>Model 2<br/>(fixed effects)</b> |
|----------------------------------------------|---------------------------------------|-------------------------------------|------------------------------------|
| <i>Gasoline price % increase (GAS)</i>       | 0.005725*                             | 0.006979**                          | 0.020079***                        |
| <i>Diesel price % increase (DSL)</i>         | -0.00471*                             | -0.006105**                         | -0.016814***                       |
| <i>LPG price % increase (LPG)</i>            |                                       |                                     |                                    |
| <i>Kerosene price % increase (KER)</i>       | 0.01253***                            | 0.01604***                          | 0.03834***                         |
| <i>Electricity price % increase (ELC)</i>    |                                       |                                     |                                    |
| <i>Compensation (COMP)</i>                   |                                       |                                     |                                    |
| <i>Annual % GDP growth (GDPG)</i>            | -0.09489***                           | -0.07014*                           | -0.05952                           |
| <i>Log annual GDP per capita (GDPPC)</i>     |                                       |                                     |                                    |
| <i>Log population (POP)</i>                  | 0.42833***                            | 0.56890***                          | 1.24134                            |
| <i>Government effectiveness (GE)</i>         |                                       |                                     |                                    |
| <i>Regulatory quality (RQ)</i>               |                                       |                                     |                                    |
| <i>Voice and Accountability (VA)</i>         |                                       |                                     |                                    |
| <i>Political Stability (PS)</i>              |                                       |                                     |                                    |
| <i>Rule of Law (RL)</i>                      |                                       |                                     |                                    |
| <i>Control of corruption (CC)</i>            |                                       |                                     |                                    |
| <i>Regime type (RT)</i>                      |                                       |                                     |                                    |
| <i>Civil Freedom (CF)</i>                    | 0.98764***                            | 1.33263***                          | 2.15625***                         |
| <i>Human Development Index (HDI)</i>         | -0.05647***                           | -0.03872**                          | 0.03979                            |
| <i>Annual % inflation (INF)</i>              |                                       |                                     |                                    |
| <i>Exporter or importer (XM)</i>             |                                       |                                     |                                    |
| <i>Constant</i>                              | -6.69125***                           | -11.32963***                        |                                    |
| <i>LR / Wald chi-square test</i>             | chi2(7) = 119.32***                   | chi2(7) = 38.25***                  | chi2(7) = 38.05***                 |
| <i>Pseudo R-squared</i>                      | 0.2293                                | N/A                                 | 0.1367                             |
| <i>AIC</i>                                   | 417.1                                 | 410.5                               | 254.3                              |
| <i>BIC</i>                                   | 449.0                                 | 446.4                               | 280.3                              |

**Table 32** Classification statistics for the preferred final social unrest model.

| <i>Model 2</i>              | <b>Value<br/>(at default cut-off of<br/>0.5)</b> | <b>Value<br/>(at cut-off of 0.378)</b> |
|-----------------------------|--------------------------------------------------|----------------------------------------|
| <i>Sensitivity</i>          | 57.04%                                           | 75.35%                                 |
| <i>Specificity</i>          | 84.88%                                           | 75.19%                                 |
| <i>Correctly classified</i> | 75.00%                                           | 75.25%                                 |

#### **5.4.1.2 Final social unrest model: results and discussion**

Table 33 presents the results from the final preferred model in terms of odd ratios for easier interpretation (Uberti, 2022). It shows that for gasoline, a one-unit percentage increase in its price during an episode of reform raises the odds of social unrest by 0.57%.<sup>26</sup> In the case of kerosene, a one-unit percentage increase in its price raises the odds of social unrest by 1.26%. These results reveal that extensive increases in the prices of both fuels during a reform, particularly kerosene, can make social unrest much more likely to occur, so countries should reform energy prices gradually. Kerosene's importance to lower-income households, with it sometimes being referred to as the "poor man's fuel" (MacRae, 2008), may explain its relatively stronger effect on the occurrence of social unrest. (The coefficient on kerosene was also very robust, being consistently significant in every single model during the general-to-specific testing down procedure.)

**Table 33** Odds ratios for the final social unrest model.

| <b>Dependent variable (DV): social unrest</b> | <b>Final model</b> |
|-----------------------------------------------|--------------------|
| <i>Gasoline % point increase (GAS)</i>        | 1.0057*            |
| <i>Diesel % point increase (DSL)</i>          | 0.9953*            |
| <i>Kerosene % point increase (KER)</i>        | 1.0126***          |
| <i>Annual GDP growth in % points (GDPG)</i>   | 0.9095***          |
| <i>Log population (POP)</i>                   | 1.5347***          |
| <i>Civil Freedom (CF)</i>                     | 2.6849***          |
| <i>Human Development Index (HDI)</i>          | 0.9451***          |
| <i>Constant</i>                               | 0.0012***          |

<sup>26</sup> While this figure may appear small, it is important to note that during episodes of energy subsidy reform, increases in fuel prices tend to be much larger than 1%. For example, a 100% increase in the gasoline price would raise the odds of unrest by 77.2% (obtained by taking the exponential of 100 multiplied by the gasoline coefficient estimate from the pooled model in Table 31).

Surprisingly, for diesel, the preferred model shows that a one-unit percentage increase in its price reduces the odds of social unrest by 0.47%. Diesel is a fuel that tends to be consumed by specific groups, like truck operators, farmers, or fishermen – and it varies from country to country. I offer two hypotheses for this unexpected result. First, it is possible that governments directly or indirectly compensate these specific groups of diesel users when raising diesel prices. For example, the government may offer some form of indirect support for farmers to compensate for higher diesel prices.<sup>27</sup> These instances of group-specific compensation are not captured in my dataset, so the negative coefficient on the diesel price increase may be indirectly capturing the impact of group-specific compensation.<sup>28</sup> My second hypothesis relates to diesel price increases being implemented as part of a wider economic transformation. As discussed in Chapter 4, studies have suggested that comprehensive energy subsidy reforms that are positioned as part of broader economic transformations may be more likely to succeed (Beaton et al., 2013; Whitley and van der Burg, 2018).

Looking beyond the energy-price-related variables, the regression analysis points to the importance of economic performance to the success of energy subsidy reform. Table 33 reveals that a one-unit percentage increase in real GDP reduces the odds of unrest by 9.05%. This result suggests that governments should take advantage of periods of fast economic growth to implement subsidy reforms, and it is in line with a recent study by Kollias and Tzeremes (2022), which demonstrated the existence of a relationship between economic downturns in Middle Eastern and Central Asian economies and general (not necessarily energy-related) social unrest.

The regression results also suggest that social unrest following energy subsidy reform is more likely to occur in countries with larger populations. Given that the population variable enters my equation in natural logs, my regression reveals that an *e*-fold (i.e., 2.78-fold) increase in the population leads to a 53.47% increase in the odds of unrest. I

---

<sup>27</sup> The International Institute for Sustainable Development (IISD, 2010) discussed examples of farmers being compensated following energy subsidy reform through value-added tax exemptions and increased prices on the agricultural commodities that they sell.

<sup>28</sup> My compensation variable only captures instances of economy-wide cash transfer compensation schemes for lower- to middle-income households.

hypothesize that countries with larger populations might be more likely to carry the conditions needed to trigger unrest. This result suggests that countries with larger populations may need to design their energy subsidy reforms relatively more carefully.

Not surprisingly, I find that civil freedom has a very strong impact on whether social unrest occurs following reform. The results show that a one-unit increase in the civil freedom index, which varies from a low of 1 to a high of 4, increases the odds of unrest by a factor of 2.68. This large value stems from the variable's relatively narrow range and the fact that countries that provide their citizens with the freedom of expression and the freedom of assembly to protest government actions are more likely to experience social unrest following reform when compared to countries in which citizens are banned (and face the threat of arrest) from protesting their government's actions.

The analysis also reveals that a one-unit increase in the HDI, which was scaled to vary from 0 to 100, reduces the odds of social unrest by 5.49%. This result shows that more developed countries, which have healthier, more educated populations with a higher standard of living, are less likely to trigger social unrest when implementing energy subsidy reforms. On the other hand, less developed countries, particularly the least developed countries that exhibit the lowest HDI values, will likely have greater difficulties implementing successful reforms. To succeed, such countries will likely need to adopt a much more gradual approach or take advantage of periods of rapid economic growth to improve their chances of avoiding social unrest.

The absence of compensation from the final model, which only included statistically significant explanatory variables, was surprising. Multiple qualitative studies have discussed the importance of compensatory measures for mitigating the adverse impacts of energy subsidy reforms on households (e.g., Laan et al., 2010; Commander, 2012; Beaton et al., 2013; Vagliasindi, 2013; Clements et al., 2013-2014; Rentschler and Bazilian, 2017a-2017b), and Chapter 4 has presented compensation as a key enabler of success. This surprising result likely stems from my analysis not capturing how effectively compensation was implemented. For example, in one country, effective compensation design might have prevented unrest, while in another country, poor compensation design might not have done so. Two critical aspects of compensation

design relate to coverage and timing, both of which were discussed in Chapter 4. In countries where compensation covered most lower-income households and was delivered before the reform, it likely prevented unrest. In countries where compensation coverage was limited and it was implemented after reform, the compensation likely did not prevent unrest. Unfortunately, I was unable to obtain information related to the timing or coverage of compensation schemes for most episodes, so my compensation variable only captures all instances of compensation, regardless of how well each one was implemented. I hypothesize that this contributed to the lack of a statistically significant coefficient for compensation in the final model.

## **5.4.2 Results for reform reversal as the dependent variable**

### ***5.4.2.1 Selecting a final model for reform reversal***

The logistic regression results for reform reversal as a dependent variable are shown in Table 34, starting with a general model with no dummy variables, given by Equation [32]. The regression revealed that compensation had to be omitted, as the variable perfectly predicted the occurrence of a reversal. In other words, all episodes of reform that culminated in a reversal did not include cash compensation, indicating that the absence of cash compensation is strongly associated with reversals. I then tested for the inclusion of year time dummies, which were not jointly significant. As for country dummies, after losing half the countries from the sample, they were also not jointly significant. Testing all dummy variables together, I confirmed that neither set was jointly significant. As was the case with the general models for social unrest, the general models for reform reversal may also be suffering from potential overfitting issues (Hosmer et al., 2013).

I also estimated panel data models. I found that the panel-level variance component, denoted by  $\rho$ , was zero for the panel general model. The LR test of whether  $\rho$  equals zero produced a p-value of 0.405, indicating to continue using the pooled estimator.

Having established that the pooled estimator is preferred and that there may be overfitting issues with the general models, I proceeded to estimate Equation [34], which was obtained by purposeful selection. The results are shown in Table 35 for different

sets of dummy variables. I started with a model with no dummies and then tested the inclusion of time and country dummies, first separately and then together. In all cases, the dummies were not jointly significant. As was the case with the general models for reversal, the purposeful selection regression results suggest that the dummies can be dropped. However, the purposeful selection model, despite including fewer explanatory variables than the general model, continued to suffer from severe multicollinearity, with a few explanatory variables exhibiting VIF values greater than ten.

I subsequently tested down from the purposeful selection model, following the general-to-specific approach, to look for a more parsimonious model. Compared to social unrest as a dependent variable, it proved more difficult to find multiple parsimonious models for reversal as a dependent variable that included only statistically significant explanatory variables. Table 36 shows only one parsimonious model, which did not suffer from any multicollinearity issues.

I compared the general, purposeful selection, and parsimonious models (using the pooled estimator) that were presented in Table 34 through Table 36 using various goodness-of-fit statistics. According to the AIC, the superior model is the purposeful selection model that includes country and time dummies. However, if I exclude models with country dummies, model 1 emerges as the superior model, a result reinforced by examining the BIC.

Proceeding with parsimonious model 1 for further analysis, I tested for time and country dummies. Both sets of dummies were not significant, whether included separately or together. I also assessed the random effects and fixed effects panel estimators for model 1. Table 36 shows the regression results, highlighting differences across all three estimators. The use of fixed effects (i.e., country dummies) led to the same loss of observations discussed previously. The Hausman test to compare fixed and random effects showed that fixed effects were preferred, in contrast to the case for the final social unrest model. However, since the fixed effects estimator leads to the loss of many observations, and since I am interested in measuring the impacts of explanatory variables like civil freedom that vary very little over time (Wooldridge, 2010), I proceeded with the pooled estimator for model 1 as the final model.

I conducted further tests on the final reversal model. Table 37 shows its sensitivity and specificity. While the rate of correctly identifying the absence of a reversal is over 99%, the rate of correctly identifying its occurrence is only 2.1%. The much stronger results for predicting the absence of a reversal stem from its much larger group size, as there were only 48 energy subsidy reform episodes that produced a reversal, and 352 episodes that did not. Given that my observations on reform reversal are heavily unbalanced, I explored the use of different cut-off points for the classification tests. As discussed previously, Hosmer et al. (2013) recommended choosing a cut-off point where the sensitivity and specificity curves approximately cross (i.e., have similar values). By changing the cut-off to 0.144, the rate of correctly identifying the occurrence of a reversal rises from 2.1% to 66.7%, at the cost of a smaller deterioration in the rate of correctly identifying the absence of a reversal from 99.7% to 65.6%. Finally, I measured the area under the ROC curve to be 0.72, indicating a final model that is acceptable at predicting outcomes correctly (Hosmer et al., 2013).

**Table 34** Estimated general models (using pooled estimator) and goodness-of-fit tests with different sets of dummy variables.

| <b>Dependent variable:<br/>reform reversal</b>   | <b>General model<br/>(no dummies)</b> | <b>General model<br/>(+ time dummies)</b> | <b>General model<br/>(+ country dummies)</b> | <b>General model<br/>(+ country &amp; time<br/>dummies)</b> |
|--------------------------------------------------|---------------------------------------|-------------------------------------------|----------------------------------------------|-------------------------------------------------------------|
| <i>Gasoline price % increase (GAS)</i>           | -0.00596                              | -0.00900                                  | -0.00153                                     | 0.02036                                                     |
| <i>Diesel price % increase (DSL)</i>             | -0.00187                              | -0.00151                                  | 0.00457                                      | -0.00994                                                    |
| <i>LPG price % increase (LPG)</i>                | 0.00493                               | 0.00590                                   | 0.02023**                                    | 0.03017***                                                  |
| <i>Kerosene price % increase<br/>(KER)</i>       | 0.01071**                             | 0.01342**                                 | 0.01404*                                     | 0.02776***                                                  |
| <i>Electricity price % increase<br/>(ELC)</i>    | 0.00110                               | -0.00080                                  | 0.00502                                      | 0.00721                                                     |
| <i>Compensation (COMP)</i>                       | Omitted                               | Omitted                                   | Omitted                                      | Omitted                                                     |
| <i>Annual % GDP growth (GDPG)</i>                | -0.08573*                             | -0.09907*                                 | -0.05256                                     | 0.00516                                                     |
| <i>Log annual GDP per capita<br/>(GDPPC)</i>     | -0.74429                              | -0.89047                                  | 5.38800                                      | 2.59676                                                     |
| <i>Log population (POP)</i>                      | 0.10487                               | 0.09247                                   | -0.49647                                     | -7.03505                                                    |
| <i>Government effectiveness (GE)</i>             | -0.78202                              | -0.85180                                  | -1.98236                                     | -5.55169*                                                   |
| <i>Regulatory quality (RQ)</i>                   | 1.34444                               | 1.59377*                                  | 0.52908                                      | 1.52811                                                     |
| <i>Voice and Accountability (VA)</i>             | 0.30335                               | 0.85044                                   | -3.22766*                                    | -7.72270                                                    |
| <i>Political Stability (PS)</i>                  | -0.25654                              | -0.42853                                  | 0.32684                                      | -0.09416                                                    |
| <i>Rule of Law (RL)</i>                          | -0.63015                              | -1.06172                                  | -0.01040                                     | -0.52515                                                    |
| <i>Control of corruption (CC)</i>                | 0.53878                               | 0.93175                                   | 1.73976                                      | 4.36665*                                                    |
| <i>Regime type (RT)</i>                          | -0.03881                              | -0.03852                                  | -0.09607                                     | -0.39608*                                                   |
| <i>Civil Freedom (CF)</i>                        | 0.53325                               | 0.17957                                   | 1.63836                                      | 5.67764*                                                    |
| <i>Human Development Index (HDI)</i>             | -0.01944                              | -0.02326                                  | -0.18877                                     | -0.17945                                                    |
| <i>Annual % inflation (INF)</i>                  | 0.00031                               | 0.00682                                   | 0.00156                                      | 0.00175                                                     |
| <i>Exporter or importer (XM)</i>                 | 1.15719**                             | 1.57496**                                 | 0.11021                                      | -0.80094                                                    |
| <i>Constant</i>                                  | 1.82451                               | 5.46257                                   | -0.80094                                     | 86.86301                                                    |
| <i>likelihood ratio (LR) chi-square<br/>test</i> | chi2(19) = 45.74                      | chi2(39) = 59.70                          | chi2(38) = 67.03                             | chi2(57) = 92.20                                            |
| <i>Pseudo R-squared</i>                          | 0.1558                                | 0.2147                                    | 0.2785                                       | 0.4094                                                      |
| <i>AIC</i>                                       | 287.8                                 | 298.3                                     | 251.7                                        | 249.0                                                       |
| <i>BIC</i>                                       | 367.6                                 | 452.0                                     | 389.8                                        | 447.1                                                       |

**Table 35** Estimated purposeful selection models (using pooled estimator) and goodness-of-fit tests with different sets of dummies.

| <i>Dependent variable:<br/>reform reversal</i>   | <i>Purposeful selection<br/>model (no dummies)</i> | <i>Purposeful selection<br/>model<br/>(+ time dummies)</i> | <i>Purposeful selection<br/>model<br/>(+ country dummies)</i> | <i>Purposeful selection<br/>model<br/>(+ country &amp; time<br/>dummies)</i> |
|--------------------------------------------------|----------------------------------------------------|------------------------------------------------------------|---------------------------------------------------------------|------------------------------------------------------------------------------|
| <i>Gasoline price % increase (GAS)</i>           |                                                    |                                                            |                                                               |                                                                              |
| <i>Diesel price % increase (DSL)</i>             |                                                    |                                                            |                                                               |                                                                              |
| <i>LPG price % increase (LPG)</i>                | 0.00158                                            | 0.00121                                                    | 0.02133**                                                     | 0.02645***                                                                   |
| <i>Kerosene price % increase<br/>(KER)</i>       | 0.00387                                            | 0.00482                                                    | 0.01437**                                                     | 0.02346**                                                                    |
| <i>Electricity price % increase<br/>(ELC)</i>    |                                                    |                                                            |                                                               |                                                                              |
| <i>Compensation (COMP)</i>                       | Omitted                                            | Omitted                                                    | Omitted                                                       | Omitted                                                                      |
| <i>Annual % GDP growth (GDPG)</i>                | -0.06195                                           | -0.04984                                                   | -0.04827                                                      | -0.02520                                                                     |
| <i>Log annual GDP per capita<br/>(GDPPC)</i>     | -0.09629                                           | -0.05556                                                   | 4.10238                                                       | 3.13277                                                                      |
| <i>Log population (POP)</i>                      | 0.09061                                            | 0.05473                                                    | 0.37036                                                       | -2.80128                                                                     |
| <i>Government effectiveness (GE)</i>             | 0.00335                                            | 0.00467                                                    | -1.74014                                                      | -4.77108*                                                                    |
| <i>Regulatory quality (RQ)</i>                   |                                                    |                                                            |                                                               |                                                                              |
| <i>Voice and Accountability (VA)</i>             | -0.07157                                           | 0.36181                                                    | -2.92667                                                      | -5.31482*                                                                    |
| <i>Political Stability (PS)</i>                  | -0.31536                                           | -0.42990                                                   | 0.56921                                                       | 0.49186                                                                      |
| <i>Rule of Law (RL)</i>                          | -0.67868                                           | -1.03986                                                   | -0.23356                                                      | -0.80601                                                                     |
| <i>Control of corruption (CC)</i>                | 0.43726                                            | 0.59473                                                    | 1.87642                                                       | 3.82193                                                                      |
| <i>Regime type (RT)</i>                          | -0.04164                                           | -0.03465                                                   | -0.10996                                                      | -0.32030                                                                     |
| <i>Civil Freedom (CF)</i>                        | 1.45838*                                           | 1.28024                                                    | 1.22613                                                       | 3.15270                                                                      |
| <i>Human Development Index (HDI)</i>             | -0.03145                                           | -0.03507                                                   | -0.16576                                                      | -0.22756                                                                     |
| <i>Annual % inflation (INF)</i>                  |                                                    |                                                            |                                                               |                                                                              |
| <i>Exporter or importer (XM)</i>                 |                                                    |                                                            |                                                               |                                                                              |
| <i>Constant</i>                                  | -4.74912                                           | -2.76645                                                   | -36.35718                                                     | 20.85207                                                                     |
| <i>likelihood ratio (LR) chi-square<br/>test</i> | chi2(13) = 33.10***                                | chi2(33) = 44.63*                                          | chi2(32) = 64.18***                                           | chi2(51) = 86.76***                                                          |
| <i>Pseudo R-squared</i>                          | 0.1128                                             | 0.0852                                                     | 0.2666                                                        | 0.3853                                                                       |
| <i>AIC</i>                                       | 288.4                                              | 301.4                                                      | 242.5                                                         | 242.4                                                                        |
| <i>BIC</i>                                       | 344.3                                              | 432.0                                                      | 359.4                                                         | 420.1                                                                        |

**Table 36** *Estimated parsimonious models (using different estimators) and goodness-of-fit tests.*

| <b>Dependent variable:<br/>reform reversal</b>   | <b>Model 1<br/>(pooled estimator)</b> | <b>Model 1<br/>(random effects)</b> | <b>Model 1<br/>(fixed effects)</b> |
|--------------------------------------------------|---------------------------------------|-------------------------------------|------------------------------------|
| <i>Gasoline price % increase (GAS)</i>           |                                       |                                     |                                    |
| <i>Diesel price % increase (DSL)</i>             |                                       |                                     |                                    |
| <i>LPG price % increase (LPG)</i>                |                                       |                                     |                                    |
| <i>Kerosene price % increase<br/>(KER)</i>       | 0.00609**                             | 0.00693**                           | 0.01436**                          |
| <i>Electricity price % increase<br/>(ELC)</i>    |                                       |                                     |                                    |
| <i>Compensation (COMP)</i>                       |                                       |                                     |                                    |
| <i>Annual % GDP growth (GDPG)</i>                | -0.06725*                             | -0.06565                            | -0.05430                           |
| <i>Log annual GDP per capita<br/>(GDPPC)</i>     |                                       |                                     |                                    |
| <i>Log population (POP)</i>                      |                                       |                                     |                                    |
| <i>Government effectiveness (GE)</i>             |                                       |                                     |                                    |
| <i>Regulatory quality (RQ)</i>                   |                                       |                                     |                                    |
| <i>Voice and Accountability (VA)</i>             |                                       |                                     |                                    |
| <i>Political Stability (PS)</i>                  |                                       |                                     |                                    |
| <i>Rule of Law (RL)</i>                          |                                       |                                     |                                    |
| <i>Control of corruption (CC)</i>                |                                       |                                     |                                    |
| <i>Regime type (RT)</i>                          |                                       |                                     |                                    |
| <i>Civil Freedom (CF)</i>                        | 0.67871**                             | 0.62132                             | -0.70446                           |
| <i>Human Development Index (HDI)</i>             | -0.05433***                           | -0.05517***                         | -0.02102                           |
| <i>Annual % inflation (INF)</i>                  |                                       |                                     |                                    |
| <i>Exporter or importer (XM)</i>                 |                                       |                                     |                                    |
| <i>Constant</i>                                  | -0.19760                              | -0.20926                            |                                    |
| <i>likelihood ratio (LR) chi-square<br/>test</i> | chi2(4) = 27.90***                    | chi2(4) = 16.44***                  | chi2(4) = 9.88**                   |
| <i>Pseudo R-squared</i>                          | 0.0950                                | N/A                                 | 0.0599                             |
| <i>AIC</i>                                       | 275.6                                 | 273.1                               | 163.0                              |
| <i>BIC</i>                                       | 295.6                                 | 297.1                               | 177.2                              |

**Table 37** Classification statistics for the final reform reversal model.

| <i>Final model</i>          | <b>Value<br/>(at default cut-off of<br/>0.5)</b> | <b>Value<br/>(at cut-off of 0.144)</b> |
|-----------------------------|--------------------------------------------------|----------------------------------------|
| <i>Sensitivity</i>          | 2.08%                                            | 66.67%                                 |
| <i>Specificity</i>          | 99.72%                                           | 65.63%                                 |
| <i>Correctly classified</i> | 88.00%                                           | 65.75%                                 |

#### **5.4.1.2 Final reform reversal model: results and discussion**

Table 38 presents the results from the final preferred model in terms of odd ratios for easier interpretation. It shows that for kerosene, a one-unit percentage increase in its price during an episode of energy subsidy reform raises the odds of a reversal by 0.61%. As discussed previously, kerosene is well-known for its importance to lower-income households, so increases in its price have a strong impact on energy poverty, possibly leading to either political pushback or the widespread type of social unrest that forces a policy reversal. (The coefficient on kerosene was also very robust, being consistently significant in most models during the general-to-specific testing down procedure, regardless of dummies included or estimator used.)

**Table 38** Odds ratios for the final reform reversal model.

| <b>Dependent variable (DV): reform reversal</b> | <b>Final model</b> |
|-------------------------------------------------|--------------------|
| <i>Kerosene % increase (KER)</i>                | 1.0061**           |
| <i>Annual GDP growth in % points (GDPG)</i>     | 0.9350*            |
| <i>Civil Freedom (CF)</i>                       | 1.9713**           |
| <i>Human Development Index (HDI)</i>            | 0.9471***          |
| <i>Constant</i>                                 | 0.8207             |

According to the final model, fuels other than kerosene do not have a statistically significant effect on the occurrence of a reversal, although for a few countries there were instances of reversals that appear to have been directly driven by gasoline or LPG price increases. In fact, when using fixed effects, the LPG price increase variable emerges as having a statistically significant effect in increasing the odds of a reversal, but this effect disappears in the final model when using the pooled estimator. The lack of a consistently significant effect for fuels other than kerosene may stem from the relatively small number of observations that led to a reversal, so there was not enough statistical power to identify significant effects for price

increases in those other fuels. Nevertheless, the results for kerosene suggest that large increases in the prices of fuels that are vital to lower-income households, which can vary from country to country, can lead to considerably higher odds of a reversal, and also the violent type of unrest that triggers such reversals.<sup>29</sup>

As was the case with the social unrest model, my results point to the importance of economic performance to the success of energy subsidy reform. Table 38 reveals that a one-unit percentage increase in real GDP reduces the odds of a reversal by 6.50% (a similar result to the 9.05% reduction in the odds of social unrest). These results demonstrate that governments should take advantage of periods of fast economic growth to implement energy subsidy reforms for better odds of success, whether from the perspective of avoiding social unrest or a policy reversal.

As was the case with the social unrest model, my results demonstrate that civil freedom has a very strong impact on whether a reversal occurs following reform. The results show that a one-unit increase in the civil freedom index, which varies from a low of 1 to a high of 4, increases the odds of a reversal twofold (compared to a 2.7-fold increase from the final social unrest model). This large increase likely stems from the fact that countries that provide their citizens with the freedom of assembly to protest government actions are more likely to experience protests that can escalate to the point of forcing governments into a reversal.

My analysis also reveals that a one-unit increase in the HDI, which was scaled to vary from 0 to 100, reduces the odds of a reversal by 5.29% (compared to a reduction of 5.49% for the odds of unrest). These results suggest that more developed countries, which have healthier, more educated populations with a higher standard of living, may have fewer people facing challenges with energy poverty (Halkos and Gkampoura, 2021), and thus fewer people to trigger the violent type of unrest that often culminates in a policy reversal. These results underscore the difficulties that developing countries, particularly the least developed countries with the lowest HDI values, will likely have in implementing successful energy subsidy reforms in comparison to more developed countries with higher HDI values.

---

<sup>29</sup> I did not distinguish between different levels of social unrest in my work. Future work could focus on building a social unrest variable with varying levels of intensity.

## 5.5 Conclusion

Despite extensive past attempts to reform energy subsidies, many countries continue to face challenges in achieving successful outcomes, with many of those attempts leading to social unrest or a subsidy reversal, two unwelcome outcomes for policymakers. These challenges may partially explain the currently enormous potential for further reform, with existing subsidies estimated at over 1 trillion USD by the IEA and IMF (Black et al., 2023; IEA, 2024). To overcome these challenges, policymakers need a better understanding of the national circumstances that influence energy subsidy reform outcomes, particularly through research that applies quantitative methods – an area where there is a big gap in the literature.

Given the surprisingly large gap in quantitative studies on the determinants of successful energy subsidy reforms in the literature, this chapter tackles this gap by applying logistic regression analysis to an original dataset that captures 400 distinct energy subsidy reform episodes implemented across 43 different countries between 1995 and 2022. Through regression analysis, I quantified the effects of 20 explanatory variables on the odds of two key outcomes: whether social unrest occurs following an energy subsidy reform and whether it gets reversed. The 20 explanatory variables include increases in various energy prices alongside variables related to the economic performance of the country, its level of human development, its governance, and its institutional quality, among other variables.

My logistic regression results for social unrest as a dependent variable reveal that gasoline and kerosene price increases are two key determinants of social unrest. For example, I find that a one-unit percentage increase in gasoline and kerosene prices during an episode of energy subsidy reform raises the odds of social unrest by 0.57% and 1.26%, respectively. Therefore, a doubling of the gasoline or kerosene price, or of both fuels simultaneously, which appears to have happened many times during past reforms, can sharply increase the odds of social unrest. These results point to the importance of implementing reforms gradually, giving consumers time to adapt to price changes, in line with my findings from Chapter 4. It also points to the potential benefits of staggering energy subsidy reforms, such that each wave or step of reform focuses on increasing the price of an important fuel like gasoline while holding the price of another important fuel like kerosene fixed. My quantitative results

are generally well aligned with the qualitative literature (e.g., Beaton et al., 2013; Clements et al., 2013; Rentschler and Bazilian, 2017a), and with my findings in Chapter 4. My logistic regression results for reform reversal as a dependent variable reveal that larger increases in kerosene prices— a key fuel for lower-income households in many countries – increase the odds of a reversal, again pointing to the importance of gradual reforms to minimize the occurrence of both social unrest and a policy reversal.

Another important determinant of both social unrest and reform reversal is annual GDP growth. I find that a one-unit percentage increase in real GDP reduces the odds of a reversal by 6.50% and the odds of social unrest by 9.05%. Therefore, for countries that are preparing to implement energy subsidy reforms, policymakers will likely have a better chance of achieving a successful outcome when launching those reforms during periods of rapid economic growth, which will likely vary among oil exporters and oil importers. This result is aligned with the qualitative literature that discusses the importance of timing (e.g., Clements et al., 2013; El-Katiri and Fattouh, 2017).

My results reveal some of the other key national circumstances that can influence energy subsidy reform outcomes. Important determinants of social unrest include the population, civil freedom, and the level of human development. With regards to reform reversal, I find civil freedom and the level of human development to be important determinants. These results link closely to the principle of “common but differentiated responsibilities and respective capabilities, in the light of different national circumstances” under the Paris Agreement (2015). Perhaps increased support from developed countries to those developing countries that face the greatest challenges in reforming energy subsidies can help improve the odds of a successful outcome. Alternatively, those developing countries may need to explore alternative policy options to achieve their climate goals or work to improve their national circumstances and capabilities before considering subsidy reform.

My quantitative analysis yields important insights that can help policymakers design and implement energy subsidy reforms in a way that minimizes the occurrence of negative outcomes, while helping countries better understand the size of the barriers that they face given their national circumstances.

## Chapter 6: Conclusions

### 6.1 Rationale for Research

Climate change is one of the defining issues facing our world. In 2015, almost 200 countries, including Saudi Arabia, ratified the Paris Agreement (2015), agreeing to limit the global average temperature increase. A portfolio of climate change policies will likely be needed to achieve the objective of the Paris Agreement (Blanchard et al., 2023), and energy subsidy reform is widely seen as a critical policy instrument within that portfolio for combatting climate change. In addition to climate benefits, energy subsidy reform has been shown to deliver fiscal, economic, and health benefits as well (Black et al., 2023).

Given its importance to the global economy and energy markets, this thesis focuses mainly on Saudi Arabia. Saudi Arabia is a G20 economy, the world's leading oil exporter (EIA, 2024f), and one of the countries with the largest energy subsidies globally, according to both the IEA (2023, 2024) and the IMF (2024). Climate Watch (2024) ranked Saudi Arabia as the world's 11<sup>th</sup> largest emitter in 2022, with a share of 1.5% of global emissions, making climate change mitigation in Saudi Arabia a crucial issue.

After regulating domestic energy prices for decades, Saudi Arabia recently implemented two major waves of energy subsidy reform. The first major episode occurred in 2016 and resulted in substantial increases in fuel, electricity, and water prices. The second major episode happened at the start of 2018 and targeted a subset of energy products. In 2022, the Saudi government announced new plans for further energy subsidy reforms (Arab News, 2022). However, Saudi Arabia, like many other countries, faces challenges in implementing those reforms, which led the government to postpone some of its announced plans. Nevertheless, gradual energy subsidy reforms have continued in Saudi Arabia in 2024 and 2025 (Riyad Capital, 2024; Arab News, 2025), but there remains significant scope for further energy subsidy reform (Aljazira Capital, 2025).

Countries worldwide face challenges in successfully implementing energy subsidy reforms. There are many barriers to implementation, such as energy subsidy reform's adverse effects on households (Fattouh and El-Katiri, 2017) and a lack of

understanding of the costs and inefficiencies of energy subsidies (Beaton and Lontoh, 2010). In some cases, these barriers have prevented countries from implementing reforms or led to the postponement of plans. In other cases, these barriers have led to widespread public opposition after the implementation of the reforms. Such opposition can arise when the reforms are designed poorly and not tailored to national circumstances.

This thesis tackles multiple research gaps to inform policymakers in Saudi Arabia about the impacts of energy subsidy reform and the factors that need to be considered to implement such reforms successfully, learning from the experiences of other countries and how their circumstances determined their reform outcomes.

## **6.2 Research Questions**

This thesis primarily seeks to inform policymakers in Saudi Arabia and support their efforts to reform energy subsidies successfully by answering four crucial research questions. First, how do consumers in Saudi Arabia respond to the changes in energy prices that result from energy subsidy reform? An understanding of how energy price changes affect energy consumption is a necessary input for measuring the impacts of subsidy reform. Second, what are the economic, fiscal, and environmental impacts of energy subsidy reform in Saudi Arabia? Quantifying these impacts is needed to support policymakers in launching such reforms. Quantification also allows policymakers to weigh the benefits of reform against the costs. After quantifying the economic, fiscal, and environmental benefits of potential reforms, the next two research questions focus on learning from the experiences of other countries to overcome the barriers to implementation and launch successful energy subsidy reforms. The third question takes a qualitative approach and asks what lessons the Saudi government can learn from past attempts at energy subsidy reform by countries around the world. The fourth question takes a quantitative approach and asks by how much do different national circumstances influence the outcomes of energy subsidy reform.

## **6.3 Summary and Implications of Results**

To answer the first research question, Chapter 2 encompasses a comprehensive energy demand modelling exercise to accurately estimate price elasticities. I

estimate 15 energy demand equations for Saudi Arabia, covering all end-use sectors and as many energy products within each sector as possible. My estimates of price elasticities cover energy products and sectors for which there were no previous estimates for Saudi Arabia. My results reveal that energy demand in Saudi Arabia is generally price inelastic. Nevertheless, I demonstrate the existence of extensive heterogeneity in price elasticities between sectors and energy products within Saudi Arabia, with long-run price elasticities varying between -0.05 and -0.60. This heterogeneity underscores the importance of using sector- and product-specific elasticity values when running further analyses, and not assuming their values.

To answer the second research question, I use the estimated price elasticities from Chapter 2 to conduct a comprehensive analysis of the economic, environmental, and fiscal impacts of energy subsidy reform in Saudi Arabia, which is presented in Chapter 3. I find that further energy subsidy reforms (based on 2018 consumption quantities and reference prices) could have produced an additional annual welfare gain of 30.7 billion 2010 USD. I also find that they could have delivered around 95 million tonnes of avoided emissions annually. These avoided emissions represent over one-third of Saudi Arabia's updated first NDC target (Kingdom of Saudi Arabia, 2021). My analysis also demonstrates the significance of the fiscal gains from further energy subsidy reforms using variations of the price-gap method. I find that further reforms, if implemented in 2018, could have resulted in an additional fiscal gain of 30.3 billion 2010 USD in that year, raising total government revenue by 15% – a significant increase. Furthermore, I refine my estimates with a method that accounts for the domestic fuel savings that result from energy subsidy reform and the impacts of additional fuel exports from Saudi Arabia on international fuel prices – two important market responses. Using this method, I demonstrate that the price-gap equation does indeed over-estimate the fiscal impacts of energy subsidy reform in Saudi Arabia, but that the fiscal gains remain large even when accounting for both market responses.

Having established the potential benefits of further energy subsidy reform in Chapter 3, I proceed to answer the third research question in Chapter 4 by drawing lessons from past attempts at energy subsidy reform. Initially, I draw the following six lessons from the literature for implementing an energy subsidy reform successfully: 1) preparing a comprehensive strategy, 2) ensuring appropriate timing, 3)

communicating with stakeholders, 4) implementing price increases gradually, 5) providing compensation, and 6) moving towards deregulated energy pricing. However, these lessons stem from reports that analyzed a small number of episodes across small groups of countries. To expand the temporal and geographical scope of countries and episodes from which to draw insights, I construct a database from news content that encompasses over 3000 news articles covering over 400 energy subsidy reforms implemented worldwide between 1995 and 2022. I then leverage this original database to expound on the lessons from the literature and draw additional insights. With regard to the first lesson, I highlight the value of preparing a comprehensive strategy using numerous examples. For the second lesson, I discuss several factors that need to be considered when deciding on an appropriate time for reform, including the weather, a factor that can have important consequences given households' essential needs for cooling or heating services. With respect to the third lesson, I investigate examples of effective communication and highlight the range of stakeholders that governments need to engage with. For the fourth lesson, I find extensive evidence reinforcing the vital role of gradual price increases. With regard to the fifth lesson, I highlight the importance of compensation design, specifically the roles of coverage and timing. For the sixth lesson, I explore examples of countries successfully transitioning to deregulated energy pricing and countries failing to do so. By studying the episodes and outcomes in my dataset, I draw further conclusions. I find that some countries may not have the capabilities or circumstances needed to reform energy prices successfully and may need to explore alternative policy options to achieve their goals – at least until their institutional capacity improves or circumstances change. My analysis also points to the importance of implementing energy subsidy reforms successfully at the first attempt. I find numerous examples of unsuccessful first attempts that made future attempts even more challenging. I also find that reforms affecting a subset of energy products, but excluding fuels like LPG and kerosene that are essential to the lowest-income households, may be more likely to succeed while also potentially improving environmental outcomes (relative to a scenario in which all fuel subsidies are reformed). Finally, I examine the actions a government can take after its attempt at energy subsidy reform leads to protests, finding that a government can use partial reversals to hold on to part of the benefits

of reform while demonstrating to stakeholders its willingness to listen and compromise.

To answer the fourth research question, I apply logistic regression analysis to my dataset to quantify how different national circumstances influence the outcomes of energy subsidy reform. For social unrest as a dependent variable, I find that large gasoline and kerosene price hikes significantly increase the odds of social unrest. For reform reversal as a dependent variable, I find that large kerosene price hikes significantly increase the odds of a reform reversal. These results point to the importance of implementing reforms gradually, giving consumers time to adapt to price changes. They also point to the importance of carefully designing energy subsidy reforms for fuels like kerosene, which are vital to lower-income households. My regression results also reveal that a one-unit percentage increase in real GDP reduces the odds of a reversal by 6.50% and the odds of social unrest by 9.05%. Therefore, policymakers in Saudi Arabia and beyond will likely have a better chance of achieving a successful outcome when launching reforms during periods of rapid economic growth, which will likely vary between oil exporters and oil importers. I also demonstrate some of the other important determinants of energy subsidy reform outcomes, including civil freedom and the level of human development. My results link closely to the principle of “common but differentiated responsibilities and respective capabilities, in the light of different national circumstances” under the Paris Agreement (2015) by quantifying how some of these national circumstances influence the odds of implementing a successful energy subsidy reform.

While this thesis focuses primarily on Saudi Arabia and supporting its energy subsidy reform efforts, many of the insights will be relevant to policymakers in other countries around the world. Fiscal and environmental drivers continue to push energy subsidy reform up the policy agenda globally, and policymakers worldwide continue to face challenges in achieving successful outcomes. In 2022 alone, energy subsidy reforms were implemented by countries as varied as Bangladesh (Paul, 2022), Haiti (CE Noticias Financieras English, 2022a), Indonesia (Associated Press Financial Wire, 2022), Kazakhstan (Eurasianet, 2022), Sri Lanka (Agence France Presse, 2022), and Tunisia (The Financial Express, 2022b). Most of these episodes triggered social unrest (Al Arabiya, 2022; CE Noticias Financieras English, 2022b; IANS-English, 2022; Widiyanto, 2022; World Socialist Web Site, 2022), while in Kazakhstan, the

reform led to widespread protests, its reversal, the resignation of the government, and a state of emergency (Al Arabiya, 2022; Sullivan, 2022).

Given that the insights presented in Chapter 4 and Chapter 5 are drawn from around 400 past attempts at energy subsidy reform worldwide, they can inform policymakers across all types of countries. Chapter 4 provides a list of lessons that any government can and should ideally follow to achieve success, while Chapter 5 provides a quantitative analysis that provides an understanding of how different national circumstances influence outcomes. The insights from Chapter 5 allow policymakers in different countries to look at their national circumstances and predict the odds of a successful outcome, helping them make important decisions around the strategy, design, and timing of their energy subsidy reform implementation.

Even though Chapter 2 (energy demand modelling) and Chapter 3 (impact analysis) focused exclusively on Saudi Arabia, the methods presented in both chapters can be applied to other countries to enable a more thorough impact analysis to support their energy subsidy reform efforts. For example, in Chapter 2, I demonstrate that for most energy products in Saudi Arabia, the trend underlying energy demand is non-linear, which implies that the use of conventional econometric methods with linear deterministic trends to estimate price elasticities may lead to biased estimates. To obtain unbiased price elasticities, which are essential for the accurate quantification of the impacts of energy subsidy reform (as I have shown in the sensitivity analyses in Chapter 3), modelers should use methods like the STSM that I use in Chapter 2 that incorporate a stochastic trend in the energy demand equations. Additionally, the equations presented in Chapter 3 provide a more nuanced approach to modelling the economic, environmental, and fiscal impacts of energy subsidy reform. With regard to the fiscal impacts, I demonstrate with a refined method how to estimate those impacts while accounting for domestic fuel savings and additional fuel exports depressing the international fuel price. While I only apply this method to Saudi Arabia, it can be applied to other oil exporters to obtain more accurate estimates of the fiscal impacts of energy subsidy reform.

While I have focused exclusively on energy subsidy reform as a policy instrument in this thesis, the insights are also relevant to policymakers – in Saudi Arabia and beyond – who are considering a carbon tax. Carbon taxes are taxes levied on fuels

based on their carbon content, which results in higher fuel prices (Hafstead and Picciano, 2017). From a household perspective, the fuel price increase resulting from a carbon tax is identical to that resulting from an equivalent energy subsidy reform, so the outcome of implementing a carbon tax will likely be influenced by the same factors discussed throughout this thesis. For example, France faced the yellow vest protests in response to fuel price hikes tied to a carbon tax, which resulted in the government cancelling the fuel price increases (CNN, 2018; Hall et al., 2018; Bejar-Garcia, 2020; Driscoll, 2023). This example illustrates how policymakers wanting to implement carbon taxes successfully must confront many of the same challenges that policymakers implementing energy subsidy reforms have been facing. Since carbon taxes and energy subsidy reforms face similar challenges, the insights that I draw from past energy subsidy reforms can also inform the design of more effective carbon tax implementation globally.

## 6.4 Future Research

My research can be extended in numerous directions in the future. With regard to energy demand modelling, future efforts can be made to incorporate both time-varying coefficients and stochastic trends, which could also be combined with recent efforts to automate the general-to-specific search process to obtain even more refined estimates of price elasticities. Furthermore, future econometric research could provide updated price elasticity estimates as Saudi Arabia undertakes massive investments to give consumers alternative public transport options (SPA, 2024), which will likely affect the future consumer response to fuel price changes.

As for the impacts of energy subsidy reform, there are other effects, such as distributional household impacts and impacts on industrial competitiveness, that can be analyzed and quantified in depth should the necessary data become available.<sup>30</sup>

With regard to the lessons from successful energy subsidy reforms, efforts can be made to expand the dataset I have constructed with more episodes and outcomes, especially for countries with limited news coverage in the three databases that I used

---

<sup>30</sup> An analysis of the distributional impacts generally requires microeconomic data on households and firms, which are generally more difficult to obtain, especially in developing countries. There can also be confidentiality issues related to firm-level data. These data challenges prevented the inclusion of a distributional impact analysis for Saudi Arabia in this thesis.

(Nexis, ProQuest, and Google). The expansion of my dataset could be achieved by pulling news content from additional news databases that were not used in this study (e.g., Factiva), including those that provide news content in languages other than English. The insights could also be refined by surveying policymakers and stakeholders to draw further nuances around the lessons and which national circumstances played the most prominent role in influencing outcomes in each country.

As for the logistic regression analysis, the dataset could also be extended to include attempts at carbon tax implementation. Logistic regression analysis could then be applied to a higher-powered dataset, allowing more insights to be extracted from the data.

All these potential research avenues could provide additional valuable information for policymakers worldwide considering the use of price-based policy instruments like energy subsidy reform to achieve national and global policy goals, including fiscal, environmental, and resource sustainability.

## References

Africa News. 2002. "Nigeria; Fuel Price Hike: a Rash of Protest." Africa News, retrieved from:

<https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:44W5-M5D0-0040-T1DB-00000-00&context=1519360>. (Published January 9, 2002).

Africa News. 2003. "Nigeria; Fuel Price Hike Sparks Protests." Africa News, retrieved from:

<https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:48XD-5060-0040-T1DS-00000-00&context=1519360>. (Published June 24, 2003).

Africa News. 2005. "Nigeria; 2 Killed, 10 Injured in Benin Fuel Protest." Africa News, retrieved from:

<https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:4H0S-VRB0-02CB-G4MN-00000-00&context=1519360>. (Published August 31, 2005).

Africa News. 2008a. "Cameroon; Unrest Spreads After Taxi Strike Ends." Africa News, retrieved from:

<https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:4RXY-9D00-TX2J-N1P4-00000-00&context=1519360>. (Published February 27, 2008).

Africa News. 2008b. "Cameroon; Government Reduces Fuel Prices." Africa News, retrieved from:

<https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:4RY5-8PY0-TX2J-N0BX-00000-00&context=1519360>. (Published February 28, 2008).

Africa News. 2008c. "Cameroon; Calm Has Now Returned." Africa News.

<https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:4S01-5C20-TX2J-N16Y-00000-00&context=1519360>. (Published March 3, 2008).

Africa News. 2008d. "Côte d'Ivoire; Ministers Take Pay Cut to Subsidise Fuel." Africa News.

<https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:4T22-WS40-TX2J-N0K1-00000-00&context=1519360>. (Published July 22, 2008).

Africa News. 2011a. "Nigeria; Forget About Fuel Subsidy Removal, Govt Urged."

Africa News, retrieved from:

<https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:5426-F1X1-JC86-C3SM-00000-00&context=1519360>. (Published October 18, 2011).

Africa News. 2011b. "Nigeria; The Unanswered Questions On Fuel Subsidy Removal." Africa News, retrieved from:

<https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:54HV-RDM1-JC86-C07C-00000-00&context=1519360>. (Published December 21, 2011).

Africa News. 2011c. "Nigeria; The Instinctive Opposition to Fuel Subsidy Removal." Africa News, retrieved from:

<https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:54KJ-GVX1-DYR8-353B-00000-00&context=1519360>. (Published December 29, 2011).

Africa News. 2012a. "Nigeria; Fuel Price Soars 116 Percent." Africa News, retrieved from:

<https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:54MD-CNN1-JC86-C1S2-00000-00&context=1519360>. (Published January 2, 2012).

Africa News. 2012b. "Nigeria; Jonathan Slashes Govt Spending After Fuel Price Hikes." Africa News, retrieved from:

<https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:54NP-72P1-JC86-C0RG-00000-00&context=1519360>. (Published January 8, 2012).

Africa News. 2012c. "Nigeria; Fuel Subsidy - 11 Killed in Bloody Protests." Africa News, retrieved from:

<https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:54P4-5451-DYR8-31BN-00000-00&context=1519360>. (Published January 10, 2012).

Africa News. 2012d. "Nigeria; Protests Suspended As Govt Cuts Fuel Price." Africa News, retrieved from:

<https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:54RD-YRF1-JC86-C2CK-00000-00&context=1519360>. (Published January 16, 2012).

Agence France Presse. 1997. "Violence erupts as Bangladesh opposition strikes against fuel prices." Agence France Presse – English, retrieved from:

<https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:3TD9-2H50-0025-F00S-00000-00&context=1519360>. (Published August 24, 1997).

Agence France Presse. 1998a. "Jakarta to raise fuel and electricity price price."

Agence France Presse – English, retrieved from:

<https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:3SM7-TVK0-0025-F2S2-00000-00&context=1519360>. (Published May 04, 1998).

Agence France Presse. 1998b. "Indonesia cuts fuel prices prices." Agence France Presse – English, retrieved from:

<https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:3SPK-H500-0025-F1D6-00000-00&context=1519360>. (Published May 15, 1998).

Agence France Presse. 2004a. "Bangladeshi opposition calls strike against fuel price rise," Agence France Presse – English, retrieved from:

<https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:4F3K-TX00-TWMD-63C3-00000-00&context=1519360>. (Published December 24, 2004 Friday).

Agence France Presse. 2004b. "India hikes fuel prices, move seen stoking inflation."

Agence France Presse – English, retrieved from:

<https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:4DR5-7WM0-TWMD-621R-00000-00&context=1519360>. (November 5, 2004 Friday).

Agence France Presse. 2005a. "Hundreds rally in Indonesia against massive fuel price hike." Agence France Presse – English, retrieved from:

<https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:4H7H-JJ70-TWMD-61WG-00000-00&context=1519360>. (Published October 1, 2005).

Agence France Presse. 2005b. "Bangladeshi opposition activists clash with police during national strike." Agence France Presse – English, retrieved from:

<https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:4H5C-R3R0-TWMD-61VB-00000-00&context=1519360>. (Published September 21, 2005).

Agence France Presse. 2008. "Ivory Coast slashes oil prices after protests: PM."

Agence France Presse – English.

<https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:4T1N-KPN0-TWMD-61BR-00000-00&context=1519360>. (Published July 20, 2008).

Agence France Presse. 2009. "India hikes petrol, diesel prices." Agence France Presse – English, retrieved from:

<https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:7W2G-8H71-2PP8-S07G-00000-00&context=1519360>. (Published July 1, 2009).

Agence France Presse. 2010a. "Iran fuel prices soar as subsidies cut." Agence France Presse – English, retrieved from

<https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:51RS-2B61-DY93-M0DX-00000-00&context=1519360>. (Published December 19, 2010).

Agence France Presse. 2010b. "Iran postpones cutting petrol subsidies." Agence France Presse – English, retrieved from:

<https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:511G-TKF1-JBV1-X25B-00000-00&context=1519360>. (Published September 15, 2010).

Agence France Presse. 2010c. "Iran again postpones cutting petrol subsidies."

Agence France Presse – English, retrieved from:

<https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:518Y-MSK1-JBV1-X3T3-00000-00&context=1519360>. (Published October 20, 2010).

Agence France Presse. 2010d. "Street protests in India over fuel price hike." Agence France Presse – English, retrieved from:

<https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:7YT7-SND0-Y95B-G4D2-00000-00&context=1519360>. (Published June 26, 2010).

Agence France Presse. 2010e. "Protestors gear up to fight Bolivian fuel price hikes."

Agence France Presse – English, retrieved from:

<https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:51V3-RBH1-DY93-M4DC-00000-00&context=1519360>. (Published December 30, 2010).

Agence France Presse. 2010f. "India deregulates petrol prices." Agence France Presse – English, retrieved from:

<https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:7YT1-TKF1-2PP8-S39K-00000-00&context=1519360>. (Published June 25, 2010).

Agence France Presse. 2013. "India partly deregulates diesel prices." Agence France Presse – English, retrieved from:

<https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:57J1-W5D1-JBV1-X000-00000-00&context=1519360>. (Published January 17, 2013).

Agence France Presse. 2016. "Kuwait raises petrol prices by more than 80%."

Agence France Presse – English, retrieved from:

<https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:5KCB-2N61-JBV1-X2HX-00000-00&context=1519360>. (Published August 1, 2016).

Agence France Presse. 2019. "Iran moves on ultra-cheap petrol." Agence France Presse – English, retrieved from

<https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:5XHD-JGY1-JBV1-X086-00000-00&context=1519360>. (Published November 15, 2019).

Agence France Presse. 2022. "Sri Lanka fuel prices up ahead of IMF talks." Agence France Presse – English, retrieved from:

<https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:657Y-DBX1-JBV1-X4JG-00000-00&context=1519360>. (Published April 18, 2022).

Agnolucci, Paolo, Carloyn Fischer, Dirk Heine, Mariza Montes De Oca Leon, Joseph Pryor, Kathleen Patroni, and Stephane Hallegatte. 2023. "Measuring Total Carbon Pricing." Policy Research Working Papers, World Bank, Washington D.C., USA.

Agnolucci, Paolo. 2010. "Stochastic Trends and Technical Change: The Case of Energy Consumption in the British Industrial and Domestic Sectors." *The Energy Journal* 31(4): 111-136.

Akanle, Olayinka, Kudus Adebayo, and Olorunlana Adetayo. 2014. "Fuel subsidy in Nigeria: contexts of governance and social protests." *International Journal of Sociology and Social Policy* 34(1/2): 88-106

Akhbaar24. 2015. Council of Ministers: "Increased Energy Prices for Fuel, Electricity, and Water." Translated from Arabic. Available at:

<https://akhbaar24.argaam.com/article/detail/255091>. (Published December 28, 2015).

Al Arabiya – English. 2018. "Saudi Arabia announces results of anti-corruption investigation." AlArabiya.net, retrieved from:

<https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:5RGJ-1961-F11P-X25S-00000-00&context=1519360>. (Published January 24, 2018).

Al Arabiya – English. 2020. "Saudi Arabia VAT tax triples to 15 pct on July 1: All you need to know amid COVID-19." AlArabiya.net. Available at:

<https://english.alarabiya.net/features/2020/06/29/Saudi-Arabia-VAT-triples-to-15-percent-on-July-1-Here-s-everything-you-need-to-know>. (Published June 29, 2020).

Al Arabiya – English. 2022. "Protests erupt in Kazakhstan after fuel price rise."

AlArabiya.net, retrieved from:

<https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:64G0-KWF1-F11P-X4C2-00000-00&context=1519360>. (Published January 04, 2022).

Al Jazeera. 2011. "Bolivia rescinds fuel subsidy cuts." Al Jazeera, retrieved from:

<https://www.aljazeera.com/news/2011/1/1/bolivia-rescinds-fuel-subsidy-cuts>

(Published January 01, 2011).

Al Yousef, Nourah. 2013. "Demand for Oil Products in OPEC Countries: A Panel Cointegration Analysis." *International Journal of Energy Economics and Policy* 3(2): 167-177.

Alarenan, Shahad, Anwar A. Gasim, and Lester C. Hunt. 2020. "Modelling industrial energy demand in Saudi Arabia." *Energy Economics* 85.

Alderman, Harold, Ugo Gentilini, and Ruslan Yemtsov. 2018. "The 1.5 Billion People Question: Food, Vouchers, or Cash Transfers?" World Bank, Washington, D.C., USA.

Aldubyan, Mohammad, and Anwar A. Gasim. 2021. "Energy price reform in Saudi Arabia: Modeling the economic and environmental impacts and understanding the demand response," *Energy Policy* 148: B.

Aleqt. 2015. "27 billion riyals in savings from energy and water price reform during 2016." Translated from Arabic. Available at:

[https://www.aleqt.com/2016/12/24/article\\_1112842.html](https://www.aleqt.com/2016/12/24/article_1112842.html). (Published December 24, 2016).

Al-Faris, Abdul Razak F. 1992. "Income and Price Elasticities of Gasoline Demand in the Organization of Arab Petroleum Exporting Countries." *The Journal of Energy and Development* 17(2): 209-223.

Al-Faris, Abdul Razak F. 1997. "Demand for Oil Products in the GCC Countries." *Energy Policy* 25(1): 55-61.

Al-Faris, Abdul Razak F. 2002. "The demand for electricity in the GCC countries." *Energy Policy* 30(2): 117-124.

Alfawzan, Ziyad and Anwar Gasim. 2019. "An empirical analysis of the welfare implications of the direct rebound effect." *Energy Efficiency* 12: 1987-2010.

Aljazira Capital. 2025. "The Potential Impacts of Feedstock Price Hikes on Petrochemical & Cement Sectors." Aljazira Capital. Available at: <https://www.aljaziracapital.com.sa/media/jn3bxjbu/energy-price-reforms-jan-25-en.pdf> (accessed April 20, 2025)

Allen, R. G. D., and A. P. Lerner. 1934. "The Concept of Arc Elasticity of Demand." *The Review of Economic Studies* 1(3): 226-230.

Al-Moneef, Majid. 2020. "Saudi Arabia's role in OPEC's evolution." Chapter 3 in the *Handbook of OPEC and the Global Energy Order*, edited by Dag Harald Claes and Giuliano Garavini. Routledge.

Alriyadh. 2015. "Council of Ministers Raises Energy Prices." Translated from Arabic. Available at: <http://www.alriyadh.com/1114224>. (Published December 28, 2015).

Al-Sahlawi, Mohammed A. 1988. "Gasoline demand: The case of Saudi Arabia." *Energy Economics* 10(4): 271-275.

Al-Sahlawi, Mohammed A. 1990. "Forecasting the Demand for Electricity in Saudi Arabia." *The Energy Journal* 11(1): 119-125.

Al-Sahlawi, Mohammed A. 1997. "The demand for oil products in Saudi Arabia." *OPEC Review* 21(1): 33-38.

Al-Sahlawi, Mohammed A. 1999. "Electricity planning with demand estimation and forecasting in Saudi Arabia." *Energy Studies Review* 9(1): 82-88.

Alyousef, Yousef and Paul Stevens. 2011. "The cost of domestic energy prices to Saudi Arabia." *Energy Policy* 39(11): 6900-6905.

Amin, Julius A. 2013. "Cameroonian Youths and the Protest of February 2008." Translated from French. *Études et essais, Cahiers d'Études africaines* 211: 677-697.

Arab News. 2017. "Citizen Account Program to help Saudis face economic changes." Arab News, Riyadh, Saudi Arabia. Available at:

<http://www.arabnews.com/node/1208256/saudi-arabia>. (Published December 13, 2017).

Arab News. 2021. "Saudi Arabia puts local price cap on gasoline as oil hits multi-year highs." Arab News, Riyadh, Saudi Arabia. Available at: <https://www.arabnews.com/node/1891801/business-economy>. (Published July 11, 2021).

Arab News. 2022. "Fuel, feedstock prices for Saudi industrial sector to be adjusted from Q4 of 2023." Arab News, Riyadh, Saudi Arabia. Available at: <https://www.arabnews.com/node/2115781/business-economy>. (Published July 3, 2022).

Arab News. 2025. "Aramco raises diesel prices in Saudi Arabia to \$0.44 per liter." Arab News, Riyadh, Saudi Arabia. Available at: <https://www.arabnews.com/node/2584936/business-economy> (Published January 1, 2025).

ArabianBusiness. 2022. "Saudi Arabia capped local gas prices in bid to protect economy, Minister of Finance Mohammed Al-Jadaan says." ArabianBusiness, retrieved from: <https://www.arabianbusiness.com/politics-economics/saudi-arabia-capped-local-gas-prices-in-bid-to-protect-economy-minister-of-finance-mohammed-al-jadaan-says>. (Published October 27, 2022).

Argaam. 2019. "Citizen's Account program to deposit SAR 2.5 bln in eligible beneficiary accounts." Argaam, retrieved from: <https://www.argaam.com/en/article/articledetail/id/613034> (Published June 10, 2019).

Asian News International. 2010. "Protests against fuel price hike continues across India." Asian News International (ANI). <https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:7YV5-0DV0-YBWY-S3J5-00000-00&context=1519360>. (Published July 1, 2010).

Asian News International. 2022. "Protest erupts in Bangladesh over record hike in fuel prices." Asian News International (ANI), retrieved from: <https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:663N-HM61-F11P-X0XP-00000-00&context=1519360>. (Published August 7, 2022).

Asian Wall Street Journal. 2001. "Police in Indonesia clash with students at fuel protests --- public transport drivers strike over higher prices." Asian Wall Street Journal Retrieved from <https://www.proquest.com/newspapers/police-indonesia-clash-with-students-at-fuel/docview/315390581/se-2>. (Published June 19, 2001).

Associated Press Financial Wire. 2022. "Indonesia hikes fuel prices by 30%, cuts energy subsidies." Associated Press Financial Wire.  
<https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:669D-KBV1-JC5B-G1P9-00000-00&context=1519360>. (Published September 3, 2022).

Associated Press International. 2003. "General strike hits Bangladesh cities and towns." Associated Press International, retrieved from:  
<https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:47PK-PD10-00BT-M47C-00000-00&context=1519360> (Published January 16, 2003).

Associated Press International. 2004. "India's new government raises gasoline, cooking gas prices." Associated Press International, retrieved from:  
<https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:4CMM-N0G0-00BT-M3D5-00000-00&context=1519360>. (Published June 15, 2004).

Atalla, Tarek N. and Lester C. Hunt. 2016. "Modelling residential electricity demand in the GCC countries," *Energy Economics* 59: 149-159

Atalla, Tarek N., Anwar A. Gasim, and Lester C. Hunt, 2018. "Gasoline Demand, Pricing Policy and Social Welfare in Saudi Arabia," *Energy Policy* 114: 123-133.

Atansah, Priscilla, Masoomah Khandan, Todd Moss, Anit Mukherjee, and Jennifer Richmond. 2017. "When do Subsidy Reforms Stick? Lessons from Iran, Nigeria, and India." CGD Policy Paper 11, Center for Global Development, Washington D.C., USA.

Bacon, Robert and Masami Kojima. 2006. "Coping with Higher Oil Prices." ESM323, World Bank, Washington D.C., USA.

Badam, Ramola Talwar. 2008. "Angry consumers in India protest fuel prices." Associated Press Online, retrieved from:  
<https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:4SP8-WR60-TWCX-P01T-00000-00&context=1519360>. (Published June 6, 2008).

Bassi, Andrea Marcello, George Pallaske, Richard Bridle, and Kavya Bajaj. 2023. "Emission Reduction via Fossil Fuel Subsidy Removal and Carbon Pricing, Creating Synergies with Revenue Recycling," *World* 4: 224-240.

BBC Monitoring Africa. 2008. "Between three to six people killed during Cameroon protest." BBC Monitoring Africa, retrieved from: <https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:4RXJ-RWV0-TX34-N1FY-00000-00&context=1519360>. (Published February 26, 2008).

BBC Monitoring South Asia. 2005. "India raises oil prices, approves trade accord with Singapore." BBC Monitoring South Asia, retrieved from: <https://www.proquest.com/wire-feeds/india-raises-oil-prices-approves-trade-accord/docview/460152008/se-2>. (Published June 20, 2005).

BBC Monitoring South Asia. 2006. "India fuel price rises lead to nationwide protest threats." BBC Monitoring South Asia, retrieved from <https://www.proquest.com/wire-feeds/india-fuel-price-rises-lead-nationwide-protest/docview/459880045/se-2>. (Published June 6, 2006).

BBC. 2019. "Ecuador repeals law ending fuel subsidies in deal to stop protests." Available at: <https://www.bbc.com/news/world-latin-america-50038126>. (Published October 14, 2019).

Bdnews24.com. 2022. "'Unprecedented' fuel price hike gives Bangladeshis a sudden jolt." bdnews24.com, retrieved from: <https://bdnews24.com/economy/n684mvkik7> (Published August 6, 2022).

Beaton, Christopher and Lucky Lontoh. 2010. "Lessons Learned from Indonesia's Attempts to Reform Fossil-Fuel Subsidies," International Institute for Sustainable Development, Winnipeg, Canada.

Beaton, Christopher, Ivetta Gerasimchuk, Tara Laan, Kerryn Lang, Damon Vis-Dunbar, and Peter Wooders. 2013. "A Guidebook to Fossil-Fuel Subsidy Reform: For Policymakers in Southeast Asia." Global Subsidies Initiative, International Institute for Sustainable Development, Geneva, Switzerland.

Beaumont, Nicola J., Margrethe Aanesen, Melanie C. Austen, Tobias Börger, James R. Clark, Matthew Cole, Tara Hooper, Penelope K. Lindeque, Christine Pascoe, and

- Kayleigh J. Wyles. 2019. "Global ecological, social and economic impacts of marine plastic." *Marine Pollution Bulletin* 142: 189-195.
- Bejar-Garcia, Carlos. 2020. "France's Yellow Vest Movement and the Global Debate on Climate Change." *Harvard International Review*, retrieved from: <https://hir.harvard.edu/frances-yellow-vest-movement-and-the-global-debate-on-climate-change/> (Published April 27, 2020)
- Belkadi, Boubkar. 2005. "Freezing weather hits Algeria amid riots over fuel price hikes." *Agence France Presse – English*, retrieved from: <https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:4FBV-V4P0-TWMD-638P-00000-00&context=1519360>. (Published January 27, 2005).
- Bhattacharyya, Subhes C. 2019. *Energy Economics: Concepts, Issues, Markets and Governance*. 2nd edition 2019. Springer.
- Black, Simon, Antung A. Liu, Ian Parry, and Nate Vernon. 2023. "IMF Fossil Fuel Subsidies Data: 2023 Update," IMF Working Paper WP/23/169.
- Blanchard, Olivier, Christian Gollier, and Jean Tirole. 2023. "The Portfolio of Economic Policies Needed to Fight Climate Change," *Annual Review of Economics* 15: 689-722.
- Blazquez, Jorge, Lester C. Hunt, Baltasar Manzano, and Axel Pierru. 2020. "The Value of Saving Oil in Saudi Arabia." *The Energy Journal* 9(1): 207-222.
- Bozorgmehr, Najmeh. 2019. "Iran raises petrol prices by 50% as US sanctions bite." FT.Com, retrieved from <https://www.proquest.com/trade-journals/iran-raises-petrol-prices-50-as-us-sanctions-bite/docview/2314430035/se-2> (Published November 14, 2019)
- BP. 2020. "Statistical Review of World Energy," BP, London, United Kingdom.
- Bridel, Anna and Lucky Lontoh. 2014. "Lessons Learned: Malaysia's 2013 Fuel Subsidy Reform," Global Subsidies Initiative, International Institute for Sustainable Development, Geneva, Switzerland.
- Brons, Martijn, Peter Nijkamp, Eric Pels, and Piet Rietveld. 2008. "A meta-analysis of the price elasticity of gasoline demand. A SUR approach." *Energy Economics* 30: 2105-2122.

Buntain, Noah, Carol M. Liebler, and Kyle Webster. 2023. "Database use, database discrepancies: Implications for content analyses of news." *Newspaper Research Journal* 44(4): 409-424.

Burniaux, Jean-Marc and Jean Chateau. 2014. "Greenhouse gases mitigation potential and economic efficiency of phasing-out fossil fuel subsidies." *International Economics* 140: 71-88.

Burns, Andrew, Calvin Djiofack Zebaze, and Dinar Prihardini. 2018. "Modeling Macroeconomic Impacts and Global Externalities." Energy Subsidy Reform Assessment Framework (ESRAF) Good Practice Note 7, Washington, D.C. : World Bank Group. Available at:

<https://documents1.worldbank.org/curated/en/815971530883640016/pdf/ESRAF-note-7-Modeling-Macroeconomic-Impacts-and-Global-externalities.pdf>

Caldara, Dario, Michele Cavallo, and Matteo Iacoviello. 2019. "Oil price elasticities and oil price fluctuations." *Journal of Monetary Economics* 103: 1-20.

CCKP. 2023. "Download Data." Climate Change Knowledge Portal, World Bank. Retrieved from <https://climateknowledgeportal.worldbank.org/download-data>. (Accessed July 17, 2023).

CE Noticias Financieras English. 2020. "Ecuador announces bands for fuel prices and more public spending cuts." CE Noticias Financieras English, retrieved from: <https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:5YY4-FXY1-DY1R-B03C-00000-00&context=1519360>. (Published May 19, 2020).

CE Noticias Financieras English. 2022a. "Haiti raises fuel prices; there are new protests. CE Noticias Financieras English." retrieved from: <https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:66CY-SJM1-JCG7-8068-00000-00&context=1519360>. (Published September 14, 2022).

CE Noticias Financieras English. 2022b. "Protests and street blockades in Haiti due to gasoline price increases." CE Noticias Financieras English, <https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:66D5-RK91-JCG7-80YM-00000-00&context=1519360>. (Published September 14, 2022).

CE Noticias Financieras English. 2022c. "Angola studies the social impact of ending fuel price subsidies." CE Noticias Financieras English, retrieved from:

<https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:671F-HY01-JCG7-82W7-00000-00&context=1519360>. (Published December 5, 2022).

CEIC. 2021. "CEIC Global Database." Available at: <https://info.ceicdata.com/en-products-global-database>. CEIC, London, United Kingdom.

Chakravorty, Ujjayant, Fereidun Fesharaki, and Shuoying Zhou. 2000. "Domestic demand for petroleum in OPEC countries." *OPEC Review* 24(1): 23-52.

Charles, Chris, Tom Moerenhout, and Richard Bridle. 2014. "The Context of Fossil-Fuel Subsidies in the GCC Region and Their Impact on Renewable Energy Development." GSI Report, Global Subsidies Initiative, Geneva, Switzerland.

Chaturvedi, Saurabh and Prasanta Sahu. 2014. "India to let market set price of diesel." *The Wall Street Journal Asia*, retrieved from <https://www.proquest.com/newspapers/india-let-market-set-price-diesel/docview/1613859925/se-2>. (Published October 20, 2014).

Chelminski, Kathryn. 2018. "Fossil Fuel Subsidy Reform in Indonesia: The Struggle for Successful Reform." Chapter 11 in *The Politics of Fossil Fuel Subsidies and Their Reform*, edited by Jakob Skovgaard and Harro van Asselt. Cambridge University Press.

Chitnis, Mona and Lester C. Hunt. 2012. "What drives the change in UK household energy expenditure and associated CO2 emissions? Implication and forecast to 2020." *Applied Energy* 94: 202-214.

Clements, Benedict, David Coady, Stefania Fabrizio, Baoping Shang, Alvar Kangur, Masahiro Nozaki, Ian Parry, Vimal Thakoor, Louis Sears, Lilla Nemeth, Trevor Alleyne, Mauricio Villafuerte, Christian Jozs, Sukhwinder Singh, and Edgardo Ruggiero, Andreas Bauer, Carlo Sdrilevich, Ozgur Demirkol, Kamal Krishna, Luc Moers, Dragana Ostojic, and Younes Zouhar. 2013. "Energy subsidy reform: lessons and implications." International Monetary Fund, Washington, D.C., USA.

Clements, Benedict, David Coady, Stefania Fabrizio, Sanjeev Gupta, and Baoping Shang. 2014. "Energy subsidies: How large are they and how can they be reformed?" *Economics of Energy & Environmental Policy* 3(1): 1-18.

Climate Watch. 2024. "Saudi Arabia." Available at: [https://www.climatewatchdata.org/countries/SAU?end\\_year=2021&start\\_year=1990](https://www.climatewatchdata.org/countries/SAU?end_year=2021&start_year=1990)

- CNN. 2018. "France to suspend fuel price hike after 'yellow vest' protests." CNN.com. Available at: <https://edition.cnn.com/2018/12/04/europe/france-yellow-vest-protests-intl/index.html>. (Published December 5, 2018).
- Coady, David, Ian W. Parry, Louis Sears, and Baoping Shang. 2015. "How Large Are Global Energy Subsidies?" IMF Working Paper, WP/15/105, IMF, Washington D.C., USA.
- Coady, David, Ian W. Parry, Louis Sears, and Baoping Shang. 2017. "How Large Are Global Energy Subsidies?" *World Development* 91: 11-27.
- Coady, David, Ian W. Parry, and Baoping Shang. 2018. "Energy Price Reform: Lessons for Policymakers." *Review of Environmental Economics and Policy* 12(2): 197-219.
- Commander, Simon. 2012. "A Guide to the Political Economy of Reforming Energy Subsidies." IZA Policy Paper 52, Institute for the Study of Labor, Bonn, Germany.
- CSP. 2023. "The Polity Project." Center for System Peace, Vienna, Virginia, USA. Available at: <https://www.systemicpeace.org/polityproject.html>
- Cuddington, John T. and Leila Dagher. 2015. "Estimating Short and Long-Run Demand Elasticities: A Primer with Energy-Sector Applications." *The Energy Journal* 36(1): 185-209.
- Dahl, Carol A. 1986. "Gasoline Demand Survey." *The Energy Journal* 7(1): 67-82.
- Dahl, Carol A. and Thomas Sterner. 1991. "Analysing gasoline demand elasticities: a survey." *Energy Economics* 13(3): 203-210.
- Dahl, Carol A. 2012. "Measuring global gasoline and diesel price and income elasticities." *Energy Policy* 41: 2-13.
- Danise, Grant, Marc Lanteigne, and Indra Overland. 2010. "Reducing Energy Subsidies in China, India, and Russia: Dilemmas for Decision Makers." *Sustainability* 2(2): 475-493.
- Davis, Lucas W. 2017. "The Environmental Cost of Global Fuel Subsidies." *The Energy Journal* 38: 7-27.
- Deutsche Presse-Agentur. 2000. "ROUNDUP: General strike in Bangladesh triggers clashes between police and pickets." Deutsche Presse-Agentur, retrieved from:

<https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:413B-7230-0094-N0BK-00000-00&context=1519360>. (Published August 30, 2000).

Deutsche Presse-Agentur. 2008. "Protests mount in Cameroon, at least seven killed." Deutsche Presse-Agentur, retrieved from:

<https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:4RY5-Y770-TXCX-V19X-00000-00&context=1519360>. (Published February 28, 2008).

Deutsche Presse-Agentur. 2012a. "Police break up Nigeria fuel price hike protests." Deutsche Presse-Agentur, retrieved from:

<https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:54MT-05G1-F02M-8177-00000-00&context=1519360>. (Published January 3, 2012).

Deutsche Presse-Agentur. 2012b. "LEAD: Thousands of Indonesians rally against planned fuel price hike." Deutsche Presse-Agentur, retrieved from:

<https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:558P-C1S1-JCKJ-J464-00000-00&context=1519360>. (Published March 27, 2012).

Devraj, Ranjit. 2004. "INDIA: FUEL PRICE HIKES SIGNAL DIFFICULTIES FOR NEW GOV'T." Global Information Network, retrieved from:

<https://www.proquest.com/wire-feeds/india-fuel-price-hikes-signal-difficulties-new/docview/457563258/se-2>. (Published June 18, 2004).

Dilaver, Zafer and Lester C. Hunt. 2011. "Industrial electricity demand for Turkey: A structural time series analysis." *Energy Economics* 33(3): 426-436.

Dilaver, Zafer. 2012. "Structural Times Series Modelling of Energy Demand." PhD Dissertation. University of Surrey. Available at:

<https://openresearch.surrey.ac.uk/esploro/outputs/doctoral/Structural-Times-Series-Modelling-of-Energy/99513513102346#file-0>.

Dimitropoulos, John, Lester C. Hunt, and Guy Judge. 2005. "Estimating underlying energy demand trends using UK annual data." *Applied Economics Letters* 12(4): 239-244.

Dow Jones Institutional News. 2012. "UPDATE: Nigeria starts controversial measure to remove fuel subsidy." Dow Jones Institutional News, retrieved from

<https://www.proquest.com/wire-feeds/update-nigeria-starts-controversial-measure/docview/2129606850/se-2>. (Published January 01, 2012).

- Driscoll, Daniel. 2023. "Populism and Carbon Tax Justice: The Yellow Vest Movement in France." *Social Problems* 70(1): 143-163.
- Durand-Lasserve, Olivier, Hossa Almutairi, Abdullah Aljarboua, Frederic Murphy, Shreekar Pradhan, and Axel Pierru. 2020. "Sectoral and Economy-Wide Effects of Domestic Energy Price Reforms in Saudi Arabia." KAPSARC Discussion Paper, KAPSARC, Riyadh, Saudi Arabia.
- ECRA. 2008. "ECRA Statistical Booklet 2008." Electricity & Cogeneration Regulatory Authority. Riyadh, Saudi Arabia.
- ECRA. 2009. "ECRA Statistical Booklet 2009." Electricity & Cogeneration Regulatory Authority. Riyadh, Saudi Arabia.
- ECRA. 2010. "ECRA Statistical Booklet 2010." Electricity & Cogeneration Regulatory Authority. Riyadh, Saudi Arabia.
- ECRA. 2011. "ECRA Statistical Booklet 2011." Electricity & Cogeneration Regulatory Authority. Riyadh, Saudi Arabia.
- ECRA. 2012. "ECRA Statistical Booklet 2012." Electricity & Cogeneration Regulatory Authority. Riyadh, Saudi Arabia.
- ECRA. 2013a. "ECRA Statistical Booklet 2013." Electricity & Cogeneration Regulatory Authority. Riyadh, Saudi Arabia.
- ECRA. 2013b. "ECRA Annual Report 2013." Electricity & Cogeneration Regulatory Authority. Riyadh, Saudi Arabia.
- ECRA. 2014. "ECRA Statistical Booklet 2014." Electricity & Cogeneration Regulatory Authority. Riyadh, Saudi Arabia.
- ECRA. 2015. "ECRA Statistical Booklet 2015." Electricity & Cogeneration Regulatory Authority. Riyadh, Saudi Arabia.
- ECRA. 2016. "ECRA Statistical Booklet 2016." Electricity & Cogeneration Regulatory Authority. Riyadh, Saudi Arabia.
- ECRA. 2017. "ECRA Statistical Booklet 2017." Electricity & Cogeneration Regulatory Authority. Riyadh, Saudi Arabia.

ECRA. 2018. "ECRA Statistical Booklet 2018." Electricity & Cogeneration Regulatory Authority. Riyadh, Saudi Arabia.

ECRA. 2019. "Electricity Tariffs." Electricity & Cogeneration Regulatory Authority. Riyadh, Saudi Arabia.

EDGAR (Emissions Database for Global Atmospheric Research). 2023. Community GHG Database, a collaboration between the European Commission, Joint Research Centre (JRC), the International Energy Agency (IEA), and comprising IEA-EDGAR CO<sub>2</sub>, EDGAR CH<sub>4</sub>, EDGAR N<sub>2</sub>O, EDGAR F-GASES version 8.0. Available at: [https://edgar.jrc.ec.europa.eu/report\\_2023#data\\_download](https://edgar.jrc.ec.europa.eu/report_2023#data_download)

EI. 2024. "Statistical Review of World Energy." Energy Institute. Available at: <https://www.energyinst.org/statistical-review>

EIA. 2023. "Saudi Arabia." Energy Information Administration, Washington D.C., USA: Available at: <https://www.eia.gov/international/analysis/country/SAU>

EIA. 2024a. "Europe Brent Spot Price FOB (Dollars per Barrel)." Energy Information Administration, Washington D.C., USA: Available at: <https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=RB RTE&f=A>

EIA. 2024b. "Spot Prices for Crude Oil and Petroleum Products." Energy Information Administration, Washington D.C., USA: Available at: [http://www.eia.gov/dnav/pet/pet\\_pri\\_spt\\_s1\\_a.htm](http://www.eia.gov/dnav/pet/pet_pri_spt_s1_a.htm)

EIA. 2024c. "U.S. Residual Fuel Oil Wholesale/Resale Price by Refiners (Dollars per Gallon)." Energy Information Administration, Washington D.C., USA: Available at: [https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=EMA\\_EP PR\\_PWG\\_NUS\\_DPG&f=A](https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=EMA_EP PR_PWG_NUS_DPG&f=A)

EIA. 2024d. "Emission Factors for Greenhouse Gas Inventories." Energy Information Administration, Washington D.C., USA: Available at: <https://www.epa.gov/system/files/documents/2024-02/ghg-emission-factors-hub-2024.xlsx>

EIA. 2024e. "Petroleum and other liquids." Energy Information Administration, Washington D.C., USA: Available at: <https://www.eia.gov/international/data/world/petroleum-and-other-liquids/annual-refined-petroleum-products-consumption>

- EIA. 2024f. "Country Analysis Brief: Saudi Arabia." Energy Information Administration, Washington D.C., USA: Available at: <https://www.eia.gov/international/analysis/country/SAU>
- EIA. 2025a. "Degree Days." Energy Information Administration, Washington D.C., USA: Available at: <https://www.eia.gov/energyexplained/units-and-calculators/degree-days.php>
- EIA. 2025b. "Saudi Arabia – Analysis." Energy Information Administration, Washington D.C., USA: Available at: [https://www.eia.gov/international/content/analysis/countries\\_long/Saudi\\_Arabia/pdf/Saudi-Arabia.pdf](https://www.eia.gov/international/content/analysis/countries_long/Saudi_Arabia/pdf/Saudi-Arabia.pdf)
- EIU. 2012. "Jordan economy: Ending of fuel price subsidies prompts angry backlash." EIU ViewsWire, retrieved from: <https://www.proquest.com/wire-feeds/jordan-economy-ending-fuel-price-subsidies/docview/1153794770/se-2>. (Published Nov 15, 2012).
- El-Katiri, Laura and Bassam Fattouh. 2017. "A Brief Political Economy of Energy Subsidies in the Middle East and North Africa." Chapter in *Combining Economic and Political Development: The Experience of MENA*, edited by Luciani Giacomo. Geneva: Graduate Institute Publications; Boston: Brill-Nijhoff.
- Ellis, Jennifer. 2010. "The Effects of Fossil-Fuel Subsidy Reform: A review of modelling and empirical studies." The Global Subsidies Initiative, International Institute for Sustainable Development, Geneva, Switzerland.
- Emirates News Agency. 2015. "New fuel prices announced for August /expanded/." Emirates News Agency (WAM), retrieved from: <https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:5GJ8-CPS1-JDJN-649J-00000-00&context=1519360>. (Published July 28, 2015).
- Epsey, Molly. 1998. "Gasoline demand revisited: an international meta-analysis of elasticities." *Energy Economics* 20: 273-295.
- Epsey, James A. and Molly Epsey. 2004. "Turning on the Lights: A Meta-Analysis of Residential Electricity Demand Elasticities." *Journal of Agricultural and Applied Economics* 36(1): 65-81.

Eurasianet. 2022. "Kazakhstan: Gas price hike fuels Zhanaozen protests." Eurasianet, retrieved from: <https://eurasianet.org/kazakhstan-gas-price-hike-fuels-zhanaozen-protests>. (Published January 03, 2022.)

Facts on File World News Digest. 1998. "Indonesian President Suharto Resigns; Protests, Riots End President's 32-Year Rule ; --Protege Habibie Sworn In As Successor." Facts on File World News Digest, retrieved from: <https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:3ST1-GMV0-000Y-N273-00000-00&context=1519360>. (Published May 21, 1998).

Facts on File World News Digest. 2000. "Nigeria: Rise in Fuel Prices Sparks Riots." Facts on File World News Digest, retrieved from: <https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:40H0-2NK0-000Y-N15H-00000-00&context=1519360>. (Published June 6, 2000).

Fattouh, Bassam, Anupama Sen, and Tom Moerenhout. 2016. "Striking the Right Balance? GCC Energy Pricing Reforms in a Low Price Environment." The Oxford Institute for Energy Studies, Oxford, UK.

Fattouh, Bassam and Laura El-Katiri. 2017. "Energy Subsidies in the Arab World." United Nations Development Programme, Regional Bureau for Arab States, Arab Human Development Report, Research Paper Series.

Fiscal Balance Program. 2016. "Fiscal Balance Program: Balanced Budget 2020." Saudi Vision 2030, Riyadh, Saudi Arabia.

Fiscal Balance Program. 2017. "Fiscal Balance Program: Balanced Budget 2020." Saudi Vision 2030, Riyadh, Saudi Arabia.

Fiscal Balance Program. 2018. "Fiscal Balance Program: 2018 update." Saudi Vision 2030, Riyadh, Saudi Arabia.

Fiscal Balance Program. 2019. "Fiscal Balance Program: 2019 Update." Saudi Vision 2030, Riyadh, Saudi Arabia.

Flochel, Thomas; Gooptu, Sudarshan. 2018. "Guidance for Comprehensive Energy Subsidy Reforms." Overview Note in *Energy Subsidy Reform Assessment Framework (ESRAF): Good Practice Notes*. World Bank, Washington, D.C. USA.

Flores, Paola. 2010. "Bolivian President Evo Morales cancels a decree that sharply raised fuel prices." The Canadian Press, retrieved from: <https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:51VC-BDX1-JCBG-905V-00000-00&context=1519360>. (Published December 31, 2010).

Fossil fuel subsidy tracker. 2024. Available at: [https://fossilfuelsubsidytracker.org/methodology/#:~:text=\(Note%3A%20beginning%202021%2C%20the,post%2Dtax%E2%80%9D%20subsidies](https://fossilfuelsubsidytracker.org/methodology/#:~:text=(Note%3A%20beginning%202021%2C%20the,post%2Dtax%E2%80%9D%20subsidies).

Freeman, Elizabeth and Gretchen Moisen. 2008. "A comparison of the performance of threshold criteria for binary classification in terms of predicted prevalence and kappa." *Ecological Modelling* 217: 48-58.

G20. 2009. "G20 Leaders Statement: The Pittsburgh Summit." G20. Available at: <http://www.g20.utoronto.ca/2009/2009communique0925.html#energy>

Gasim, Anwar and Mohammad Aldubyan. 2020. "What is behind the dramatic fall in gasoline prices?" KAPSARC Instant Insight, KAPSARC, Riyadh, Saudi Arabia.

Gasim, Anwar and Walid Matar. 2023. "Revisiting Energy Subsidy Calculations: A Focus on Saudi Arabia." *The Energy Journal* 44(1): 245-276.

Gasim, Anwar, Paolo Agnolucci, Paul Ekins, and Vincenzo De Lipsis. 2023. "Modeling final energy demand and the impacts of energy price reform." *Energy Economics* 120.

GASTAT. 2022. "Export Statistics." Annual Reports, The Saudi General Authority for Statistics. Available at: <https://www.stats.gov.sa/en/211>

GASTAT. 2024. "Population 2010 – 2022." Translated from Arabic. GASTAT, Available at: <https://portal.saudicensus.sa/portal/public/1/15/101462?type=TABLE>

Gault, John, Charles Spierer, Jean-Luc Bertholet, and Bahman Karbassioun. 1999. "How does OPEC allocate quotas?" *Journal of Energy Finance & Development* 4(2): 137-148.

Gloystein, Henning. 2019. "Oil prices hover near 2019 highs after U.S. ends all Iran sanction waivers." Reuters. Available at: <https://www.reuters.com/article/global-oil/oil-prices-hover-near-2019-highs-after-u-s-ends-all-iran-sanction-waivers-idUSL3N22505B/>. (Published April 23, 2019).

- Google. 2023. "Google News," Available at: <https://news.google.com/>
- Gooptu, Sudarshan. 2018. "Good Practice Note 2: Assessing the Fiscal Cost of Subsidies and Fiscal Impact of Reform." Energy Sector Reform Assessment Framework (ESRAF), Energy Sector Management and Assistance Program (ESMAP), World Bank, Washington D.C., USA.
- Government of the Kingdom of Saudi Arabia. 2025. "Energy and Water Price Reforms Executive Committee." Available at: <https://my.gov.sa/en/agencies/17975> (accessed April 20, 2025).
- Greenhouse Gas Protocol. 2024. "Policy and Action Standard." Available at: <https://ghgprotocol.org/policy-and-action-standard>
- Guillaume, Dominique, Roman Zyteck, and Mohammad Reza Farzin. 2011. "Iran—The Chronicles of Subsidy Reform." IMF Working Paper, International Monetary Fund, Washington, D.C., USA.
- Hafstead, Marc and Paul Picciano. 2017. "Calculating Various Fuel Prices under a Carbon Tax." Resources, Available at: <https://www.resources.org/common-resources/calculating-various-fuel-prices-under-a-carbon-tax/>
- Halkos, George E. and Eleni-Christina Gkampoura. 2021. "Evaluating the effect of economic crisis on energy poverty in Europe." *Renewable and Sustainable Energy Reviews* 144.
- Hall, Ben, Harriet Agnew, and David Keohane. 2018. "Macron cancels fuel tax increase after 'gilets jaunes' protests." Financial Times, retrieved from: <https://www.ft.com/content/bd880bf8-f8a5-11e8-8b7c-6fa24bd5409c> (Published December 6, 2018).
- Harvey, Andrew C. 1989. *Forecasting, Structural Time Series Models and the Kalman Filter*. Cambridge University Press.
- Harvey, Andrew C. 2006. "Forecasting with Unobserved Components Time Series Models." Chapter 7 in *Handbook of Economic Forecasting, Volume 1*, edited by Graham Elliott, Clive W.J. Granger, and Allan Timmermann. Elsevier.
- Harvey, Andrew C. 1997. "Trends, Cycles and Autoregressions." *The Economic Journal* 107(440): 192-201

Harvey, Andrew C. and Siem Jan Koopman. 1992. "Diagnostic Checking of Unobserved-Components Time Series Models." *Journal of Business & Economic Statistics* 10(4): 377-389.

Harvey, Andrew C., Siem Jan Koopman, and Neil Shephard. 2004. *State Space and Unobserved Component Models: Theory and Applications*. Cambridge University Press.

Hassan, Hazlin. 2010. "KL may be forced to cut subsidies; Fuel, gas, electricity grants face cut after record fiscal deficit." *The Straits Times* (Singapore), retrieved from:

<https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:7YJ4-0CM0-Y9SB-T54P-00000-00&context=1519360> (Published May 25, 2010).

Havranek, Tomas, Zuzana Irsova, and Karel Janda. 2012 "Demand for gasoline is more price-inelastic than commonly thought." *Energy Economics* 34: 201-207.

Hertog, Steffen. 2017. "The Political Economy of Distribution in the Middle East: Is There Scope for a New Social Contract?" *Combining Economic and Political Development* 7.

Hidrobo, Melissa, John Hoddinott, Amber Peterman, Amy Magolies, and Vanessa Moreira. 2014. "Cash, food, or vouchers? Evidence from a randomized experiment in northern Ecuador." *Journal of Development Economics* 107: 144-156.

Hill, Hal. 2013. "The Political Economy of Policy Reform: Insights from Southeast Asia." *Asian Development Review* 30(1): 108-130.

Hines, James R. Jr. 1999. "Three sides of Harberger triangles." *Journal of Economic Perspectives* 13(2): 167-188.

Hosan, Shahadat, Kanchan Kumar Sen, Md. Matiar Rahman, Shamal Chandra Karmaker, Andrew J. Chapman, Bidyut Baran Saha. 2023. "Evaluating the mediating role of energy subsidies on social well-being and energy poverty alleviation in Bangladesh." *Energy Research & Social Science* 100.

Hosmer, David W, Stanley Lemeshow, and Rodney X Sturdivant. 2013. *Applied Logistic Regression*. Third Edition. Hoboken, N.J: Wiley.

Hunt, Lester C. and Yasushi Ninomiya. 2003. "Unravelling Trends and Seasonality: A Structural Time Series Analysis of Transport Oil Demand in the UK and Japan." *The Energy Journal* 24(3): 63-96.

Hunt, Lester C., Guy Judge, and Yasushi Ninomiya. 2003 . "Underlying trends and seasonality in UK energy demand: a sectoral analysis." *Energy Economics* 25(1): 93-118.

Hutcherson, Kimberly. 2018. "Saudi Arabia issues its first driver's licenses to women." CNN.com, retrieved from:  
<https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:5SGM-G2W1-DY60-M1S7-00000-00&context=1519360>. (Published June 4, 2018).

IANS-English. 2022. "Sri Lanka: One dead, 12 hurt as police fire at anti-fuel price hike protesters." IANS-English, retrieved from:  
<https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:6587-G2F1-JBYT-H4C6-00000-00&context=1519360>. (Published April 19, 2022).

IEA, OPEC, OECD, and World Bank. 2010. "Analysis of the Scope of Energy Subsidies and Suggestions for the G-20 Initiative." Joint Report Prepared for submission to the G-20 Summit Meeting in Toronto, Canada.

IEA, OPEC, OECD, and World Bank. 2011. "Joint report by IEA, OPEC, OECD and World Bank on fossil-fuel and other energy subsidies: An update of the G20 Pittsburgh and Toronto Commitments." Prepared for the G20 Meeting of Finance Ministers and Central Bank Governors in Paris, France, and the G20 Summit in Cannes, France.

IEA. 2005. "Energy Statistics Manual." International Energy Agency, Paris, France.

IEA. 2006. "Carrots and Sticks: Taxing and Subsidising Energy." International Energy Agency, Paris, France.

IEA. 2020. "World Energy Statistics." International Energy Agency, Paris, France.

IEA. 2021. "Extended World Energy Balances." International Energy Agency, Paris, France.

IEA. 2023. "Fossil Fuels Consumption Subsidies 2022." International Energy Agency, Paris, France. Available at: <https://www.iea.org/reports/fossil-fuels-consumption-subsidies-2022>

IEA. 2024. "Energy Subsidies." International Energy Agency, Paris, France. Available at: <https://www.iea.org/topics/energy-subsidies>

IHS Markit. 2021. "Petrochemical Industry Overview: Chemical Economics Handbook." IHS Markit, London, United Kingdom.

IMF. 2011a. "World Economic Outlook: Tensions from the Two-Speed Recovery: Unemployment, Commodities, and Capital Flows." International Monetary Fund, Washington D.C., USA.

IMF. 2011b. "Regional Economic Outlook: Middle East and Central Asia." International Monetary Fund, Washington D.C., USA.

IMF. 2017. "In the Trenches: Overcoming Resistance: Ibrahim Saif discusses why building consensus is key to successful energy subsidy reform." International Monetary Fund, Washington D.C., USA.

IMF. 2024. "Energy Subsidy Template." Version: January 2024. International Monetary Fund, Washington D.C., USA. Available at: <https://www.imf.org/-/media/Files/Topics/energy-subsidies/EXTERNALfuelsubsidiestemplate2023new.ashx>

Inchauste, Gabriela and David G. Victor. 2017. "Chapter 1: Introduction" in *The Political Economy of Energy Subsidy Reform*, edited by Gabriela Inchauste and David G. Victor. World Bank Group, Washington D.C., USA.

IISD. 2010. "A citizens' guide to energy subsidies in Malaysia." Published by the International Institute for Sustainable Development, Geneva, Switzerland.

Jadwa Investment. 2015. "Saudi Arabia's 2016 fiscal budget." Jadwa Investment. Available at: [https://www.jadwa.com/sites/default/files/2022-01/20160114\\_2016-Budget%20%284%29.pdf](https://www.jadwa.com/sites/default/files/2022-01/20160114_2016-Budget%20%284%29.pdf)

Jazuli, Muhamad Rosyid, Ine Steenmans, Yacob Mulugetta. 2021. "Navigating policy dilemmas in fuel-subsidy reductions: learning from Indonesia's experiences." *Sustainability: Science, Practice and Policy*, 17(1): 391-403.

JODI. 2021. "The JodiOil World Database." Jodi, Riyadh, Saudi Arabia. Available at: <http://www.jodidata.org/oil/>

Jones, Clifton T. 1994. "Accounting for technical progress in aggregate energy demand." *Energy Economics* 16(4): 245-252.

KAPSARC. 2020. "The Future of Cooling in Saudi Arabia: Technology, Market and Policy Options." KAPSARC Workshop Brief, KS--2020-WB08, KAPSARC, Riyadh, Saudi Arabia.

Karanfil, Fatih, and Axel Pierru. 2021. "The Opportunity Cost of Domestic Oil Consumption for an Oil Exporter: Illustration for Saudi Arabia." *Energy Economics* 96: 1-12.

Karimi, Nasser. 2010. "Police in Iran streets as subsidies are cut." Associated Press Financial Wire, retrieved from: <https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:51RS-2B61-DYN6-W553-00000-00&context=1519360>. (Published December 19, 2010).

Karstens, Mikaela, Michael J. Soules, and Nick Dietrich. 2023. "On the Replicability of Data Collection Using Online News Databases," *PS: Political Science & Politics* , 56(2): 265-272.

Kaufmann, Daniel, Aart Kraay, and Massimo Mastruzzi. 2010. "The Worldwide Governance Indicators: Methodology and Analytical Issues." World Bank Policy Research Working Paper No. 5430, World Bank, Washington D.C., USA. Available at SSRN: <https://ssrn.com/abstract=1682130>

Kazmin, Amy. 2010. "India ends control of petrol prices in bid to cut subsidy." Financial Times, retrieved from: <https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:7YT1-G850-Y8T3-019X-00000-00&context=1519360>. (Published June 26, 2010).

Kingdom of Saudi Arabia. 2015. "The Intended Nationally Determined Contribution of the Kingdom of Saudi Arabia under the UNFCCC." Kingdom of Saudi Arabia.

Kingdom of Saudi Arabia. 2021. "Updated First Nationally Determined Contribution." Kingdom of Saudi Arabia.

Kojima, Masami. 2016. "Fossil Fuel Subsidy and Pricing Policies: Recent Developing Country Experience." World Bank Policy Research Working Paper WSP7531, World Bank, Washington D.C., USA.

Kojima, Masami. 2017. "Identifying and Quantifying Energy Subsidies." Energy Subsidy Reform Assessment Framework (ESRAF) Good Practice Note 1. ESMAP Paper. World Bank. Washington, D.C., USA.

Kokoski, Mary F., and V. Kerry Smith. 1987. "A General Equilibrium Analysis of Partial-Equilibrium Welfare Measures: The Case of Climate Change." *The American Economic Review* 77, no. 3 (1987): 331–41. <http://www.jstor.org/stable/1804098>.

Kollias, Christos and Panayiotis Tzeremes. 2022. "The nexus between social unrest and economic growth in Middle East and Central Asia countries." *Review of Economics and Political Science* 7(2): 74-86.

Kolstad, Charles D. 2011. *Intermediate Environmental Economics*. International second edition. Oxford University Press, Inc.

Koopman, S. J., Harvey, A.C., Doornik, J. A., and Shephard N., 2007. *STAMP Version 8 Econometric Software*. Timberlake Consultants, London, UK.

Koplow, Doug. 2009. "Measuring Energy Subsidies Using the Price-Gap Approach: What Does It Leave Out?" International Institute for Sustainable Development, Winnipeg, Canada.

Kouris, George. 1983. "Energy Demand Elasticities in Industrialized Countries: A Survey." *The Energy Journal* 4(3): 73-94.

Kpodar, Kangni and Patrick A. Imam. 2020. "To pass (or Not to Pass) Through International Fuel Price Changes to Domestic Fuel Prices in Developing Countries: What Are the Drivers?" IMF Working Paper WP/20/194, International Monetary Fund, Washington D.C., USA.

Krane, Jim. 2013. "Stability versus Sustainability: Energy Policy in the Gulf Monarchies." *The Energy Journal* 36(4).

Krane, Jim. 2019. "Energy Governance in Saudi Arabia: An Assessment of the Kingdom's Resources, Policies, and Climate Approach." Center for Energy Studies, Rice University's Baker Institute for Public Policy, Houston, Texas, USA. Available

at: <https://www.bakerinstitute.org/sites/default/files/2019-01/import/ces-pub-saudienergy-011819.pdf>

Krane, Jim, Walid Matar, and Francisco Monaldi. 2020. "Fossil Fuel Subsidy Reform Since the Pittsburgh G20: A Lost Decade?" Center for Energy Studies, Rice University's Baker Institute for Public Policy, Houston, Texas, USA. Available at: <https://www.bakerinstitute.org/research/fossil-fuel-subsidy-reform-pittsburgh-g20-lost-decade>

Kuehl, Jonas, Andrea M. Bassi, Philip Gass, and Georg Pallaske. 2021. "Cutting Emissions Through Fossil Fuel Subsidy Reform and Taxation." GSI Report, Global Subsidies Initiative, International Institute for Sustainable Development, Geneva, Switzerland.

Kumar, Manmohan and Jaejoon Woo. 2010. "Public debt and growth." Fiscal Affairs Department, IMF Working Paper, WP/10/174, International Monetary Fund, Washington D.C., USA.

Laan, Tara, Christopher Beaton, and Bertille Presta. 2010. "Strategies for Reforming Fossil-Fuel Subsidies: Practical lessons from Ghana, France and Senegal." Global Subsidies Initiative, International Institute for Sustainable Development, Geneva, Switzerland.

Labandeira, Xavier, Jose M. Labeaga, and Xiral Lopez-Otero. 2017. "A meta-analysis on the price elasticity of energy demand." *Energy Policy* 102: 549-568.

Lahn, Glada and Paul Stevens. 2011. "Burning Oil to Keep Cool: The Hidden Energy Crisis in Saudi Arabia." Chatham House, London, UK.

Lapper, Richard. 2005. "Bolivian businesses demand scrapping of fuel price rise." Financial Times, retrieved from: <https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:4F9B-NJX0-TW84-P32K-00000-00&context=1519360>. (Published January 21, 2005).

Lipin, Michael. "Iran's November Gas Price Hike Fails to Ease Fuel Smuggling to Pakistan." Voice of America News, retrieved from <https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:5Y7B-G1N1-DYVR-P1V4-00000-00&context=1519360>. (Published February 15, 2020).

Lockwood, Matthew. 2015. "Fossil Fuel Subsidy Reform, Rent Management and Political Fragmentation in Developing Countries." *New Political Economy* 20(4): 475-494.

MacRae, Penny. 2008. "India hikes fuel prices, stirs political anger, inflation worries." Agence France Presse – English, retrieved from:  
<https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:4SNV-Y8R0-TWMD-60RP-00000-00&context=1519360>. (Published June 4, 2008).

Malaysia General News. 2010. "SUBSIDY CUTS ON CONTROLLED ITEMS WILL NOT BURDEN THE PEOPLE - IDRIS JALA." Malaysia General News, retrieved from:  
<https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:7YKP-4NM0-Y9M2-S148-00000-00&context=1519360>. (Published May 27, 2010).

Mankiw, Gregory. 2023. *Principles of Economics*. South-Western, Cengage Learning.

Mapstone, Naomi. 2010. "Unions strike as Bolivia lifts fuel subsidy." FT.com, retrieved from:  
<https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:51TB-4YG1-JCM7-G1BK-00000-00&context=1519360>. (Published December 27, 2010).

Matar, Walid, and Murad Anwer. 2017. "Jointly reforming the prices of industrial fuels and residential electricity in Saudi Arabia." *Energy Policy* 109: 747-756.

Matar, Walid, Frederic Murphy, Axel Pierru, and Bertrand Rioux. 2015. "Lowering Saudi Arabia's fuel consumption and energy system costs without increasing end consumer prices," *Energy Economics* 49: 558-569.

McCulloch, Neil, Davide Natalini, Naomi Hossain, and Patricia Justino. 2022. "An exploration of the association between fuel subsidies and fuel riots," *World Development* 157.

McCulloch, Neil, Tom Moerenhout, and Joonseok Yang. 2021. "Fuel subsidy reform and the social contract in Nigeria: A micro-economic analysis." *Energy Policy* 156.

Merriam-Webster. 2024. "Subsidy." In Merriam-Webster.com dictionary. Available at:  
<https://www.merriam-webster.com/dictionary/subsidy>

Metcalf, Gilbert E. 2017. "Implementing a Carbon Tax." RFF report, Resources For the Future, Washington D.C., USA.

Mikayilov, Jeyhun I., Frederick L. Joutz, and Fakhri J. Hasanov. 2020a. "Gasoline demand in Saudi Arabia: are the price and income elasticities constant?" *Energy Sources, Part B: Economics, Planning, and Policy* 15(4): 211-229.

Mikayilov, Jeyhun I., Fakhri J. Hasanov, Waheed Olagunju, and Mohammad H. Al-Shehri. 2020b. "Electricity demand modeling in Saudi Arabia: Do regional differences matter?" *The Electricity Journal* 33: 1-7.

Mikayilov, Jeyhun I., Abdulelah Darandary, Ryan Alyamani, Fakhri J. Hasanov, and Hatem Alatawi. 2020c. "Regional heterogeneous drivers of electricity demand in Saudi Arabia: Modeling regional residential electricity demand?" *Energy Policy* 146.

Moerenhout, Tom, and Tristan Irschlinger. 2020. "Exploring the Trade Impacts of Fossil Fuel Subsidies." GSI Report, Global Subsidies Initiative, Geneva, Switzerland.

Moerenhout, Tom, Nikos Vezanis, and Chris Westling. 2017. "Navigating Political Hurricanes in the MENA Region: Energy Pricing Reform in a Context of Changing Social Contracts." Center on Global Energy Policy, Columbia University.

Moerenhout, Tom. 2022. "Energy Subsidies." Chapter 27 in *The Palgrave Handbook of International Energy Economics*, edited by Manfred Hafner and Giacomo Luciani. Palgrave Macmillan.

Morrill, John E. 1983. "A Mathematician's Brief Excursion into Economic History—The Concept of ARC Elasticity of Demand." *The American Economist* 27(1): 47-53.

Moury, Catherine and Elisabetta De Giorgi. 2015. "Introduction: Conflict and Consensus in Parliament during the Economic Crisis." *The Journal of Legislative Studies* 21(1), 1-13.

Mustaza, Masami. 2010. "All-round support for cutbacks." New Straits Times (Malaysia), retrieved from:

<https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:7YKG-7RY0-Y9KF-Y4HP-00000-00&context=1519360>. (Published May 28, 2010).

Namaa Zone. 2024. "Aramco raises diesel prices in Saudi Arabia by 53% to 1.15 riyals per litre." Translated from Arabic. Available at:

<https://namaazone.com/en/blog/%D8%A3%D8%B1%D8%A7%D9%85%D9%83%D9%88-%D8%AA%D8%B1%D9%81%D8%B9-%D8%A3%D8%B3%D8%B9%D8%A7%D8%B1-%D8%A7%D9%84%D8%AF%D9%8A%D8%B2%D9%84-%D9%81%D9%8A-%D8%A7%D9%84%D8%B3%D8%B9%D9%88%D8%AF%D9%8A%D8%A9-53-%D8%A5%D9%84%D9%89-1-15-%D8%B1%D9%8A%D8%A7%D9%84-%D9%84%D9%84%D8%AA%D8%B1>

Natalini, Davide, Giangiacomo Bravo, and Edward Newman. 2020. "Fuel riots: definition, evidence and policy implications for a new type of energy-related conflict." *Energy Policy* 147.

Neriem, Vivian. 2021. "Saudi Arabia Eases Subsidy Cuts With Gasoline Price Ceiling." *Bloomberg*, retrieved from: <https://www.bloomberg.com/news/articles/2021-07-10/saudi-arabia-softens-subsidy-cuts-with-gasoline-price-ceiling>. (Published July 10, 2021).

Nexis, 2023a. "Nexis." LexisNexis, New York, USA. Available at <https://www.lexisnexis.com/en-us/professional/research/nexis.page>

Nexis, 2023b. "About LexisNexis." LexisNexis, New York, USA. Available at: <https://www.lexisnexis.com/en-us/about-us/about-us.page>

Obaid, Ruba. " 'Citizen Account Program' to help Saudi face economic changes," *Arab News*, retrieved from <https://www.arabnews.com/node/1208256/saudi-arabia>. (Published December 13, 2017).

OECD. 2024. "Crude Petroleum," *Observatory of Economic Complexity*, available at: <https://oec.world/en/profile/hs/crude-petroleum>

OECD. 2013. "Inventory of estimated budgetary support and tax expenditures for fossil fuels 2013." OECD, Paris, France. Available at: [https://www.oecd.org/en/publications/inventory-of-estimated-budgetary-support-and-tax-expenditures-for-fossil-fuels-2013\\_9789264187610-en.html](https://www.oecd.org/en/publications/inventory-of-estimated-budgetary-support-and-tax-expenditures-for-fossil-fuels-2013_9789264187610-en.html)

OECD/IEA. 2021. "Update on recent progress in reform of inefficient fossil-fuel subsidies that encourage wasteful consumption." Available at: [www.oecd.org/fossil-fuels/publicationsandfurtherreading/OECD-IEA-G20-Fossil-Fuel-Subsidies-Reform-Update-2021.pdf](http://www.oecd.org/fossil-fuels/publicationsandfurtherreading/OECD-IEA-G20-Fossil-Fuel-Subsidies-Reform-Update-2021.pdf).

- Oil Daily. 2008. "India hikes fuel prices." Oil Daily, retrieved from: <https://www.proquest.com/trade-journals/india-hikes-fuel-prices/docview/199149580/se-2>. (Published February 14, 2008).
- Olabisi, Michael, David L. Tschirley, David Nyange, and Titus Awokuse. 2019. "Energy demand substitution from biomass to imported kerosene: Evidence from Tanzania." *Energy Policy* 130: 243-252.
- OPEC. 2024. "Saudi Arabia facts and figures." OPEC. Available at: [https://www.opec.org/opec\\_web/en/about\\_us/169.htm](https://www.opec.org/opec_web/en/about_us/169.htm)
- Overland, Indra, Beni Suryadi, and U Thoun Win. 2016. "Energy Subsidy Reform: An International Comparative Perspective on Myanmar." Joint Report by the Myanmar Institute for Strategic and International Studies (MISIS) and the Norwegian Institute of International Affairs (NUPI).
- Oxford English Dictionary. 2024. "subsidy (n.), sense 3.c," March 2024, <https://doi.org/10.1093/OED/2188676493>.
- OxResearch Daily Brief Service. 2000. "ECUADOR: Noboa sweetens fuel-hike bill." OxResearch Daily Brief Service, retrieved from: <https://www.proquest.com/wire-feeds/ecuador-noboa-sweetens-fuel-hike-bill/docview/192317831/se-2>. (Published May 31, 2000).
- Oyo, Remi, 2000. "POLITICS-NIGERIA: GOVERNMENT EASES FUEL PRICE HIKES." IPS-Inter Press Service, retrieved from: <https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:40GS-5P00-001G-V1SH-00000-00&context=1519360>. (Published June 13, 2000).
- Palau, Anna M., Luz Muñoz Márquez & Laura Chaqués-Bonafont. 2015. "Government–Opposition Dynamics in Spain under the Pressure of Economic Collapse and the Debt Crisis." *The Journal of Legislative Studies* 21(1): 75-95.
- Paris Agreement. 2015. Available at: <https://unfccc.int/process-and-meetings/the-paris-agreement>
- Parry, Ian W.H., Dirk Heinze, Eliza Lis, and Shanjun Li. 2014. "Getting Energy Prices Right: From Principle to Practice." International Monetary Fund, Washington D.C., USA.

Paul, Ruma. 2022. "Bangladesh announces fuel price jump, stokes inflation fears." Reuters, retrieved from: [https://www.reuters.com/markets/commodities/bangladesh-announces-fuel-prices-jump-stokes-inflation-fears-2022-08-06/#:~:text=DHAKA%2C%20Aug%20%20\(Reuters\),in%20the%20world%20for%20years.\(Published%20August%2006,%202022\).](https://www.reuters.com/markets/commodities/bangladesh-announces-fuel-prices-jump-stokes-inflation-fears-2022-08-06/#:~:text=DHAKA%2C%20Aug%20%20(Reuters),in%20the%20world%20for%20years.(Published%20August%2006,%202022).)

Perloff, Jeffrey M. 2023. *Microeconomics*. Ninth Edition. Pearson Education Limited, United Kingdom.

Pizer, William, Dallas Burtraw, Winston Harrington, Richard Newell, and James Sanchirico. 2006. "Modeling Economy-Wide vs Sectoral Climate Policies Using Combined Aggregate-Sectoral Models." *The Energy Journal* 27(3): 135–68.

Plante, Michael. 2013. "The long-run macroeconomic impacts of fuel subsidies." *Journal of Development Economics* 107: 129-143.

Prina, Matteo Giacomo, Giampaolo Manzolini, David Moser, Benedetto Nastasi, Wolfram Sparber. 2020. "Classification and challenges of bottom-up energy system models - A review." *Renewable and Sustainable Energy Reviews* 129.

Prince Rupert Daily News. 2008. "Fuel price hikes prompt protests as subsidies cut." Prince Rupert Daily News (British Columbia), retrieved from: <https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:4SP3-38B0-TX77-C0VJ-00000-00&context=1519360>. (Published June 5, 2008).

ProQuest. 2023. "News and Newspapers." ProQuest. Available at: <https://about.proquest.com/en/content-solutions/news/>

Rentschler, Jun and Morgan Bazilian. 2017a. "Principles for Designing Effective Fossil Fuel Subsidy Reforms." *Review of Environmental Economics and Policy* 11(1): 138–155.

Rentschler, Jun and Morgan Bazilian. 2017b. "Reforming fossil fuel subsidies: drivers, barriers and the state of progress." *Climate Policy* 17(7): 891–914.

Reuters. 2012. "Nigeria Unions suspend strike after fuel price cut." Reuters. Available at: <https://www.reuters.com/article/us-nigeria-strike/nigeria-unions-suspend-strike-after-fuel-price-cut-idUSTRE80F0WR20120116>. (Published January 16, 2012).

Rice, Xan. 2012. "Nigeria partially reinstates fuel subsidy." FT.com, retrieved from: <https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:54RC-HKM1-JCM7-G11M-00000-00&context=1519360>. (Published January 16, 2012).

Riyad Capital. 2024. "Saudi Aramco Raises Feedstock & Fuel Prices." Riyad Capital, Riyadh, Saudi Arabia. Available at: [https://www.riyadcapital.com/documents/671358/3985789/Energy%20Price%20Update\\_Jan%202024.pdf/7269cf4b-f79f-640c-c643-eb66a68a901](https://www.riyadcapital.com/documents/671358/3985789/Energy%20Price%20Update_Jan%202024.pdf/7269cf4b-f79f-640c-c643-eb66a68a901) (Published January 7, 2024).

Saleh Wafaa and Areej Malibari. 2021. "Saudi Women and Vision 2030: Bridging the Gap?" *Behavioral Sciences (Basel)* 11(10):132.

Salehi-Isfahami, Djavad. 2019. "Iran's gasoline price hike misses lesson from Iran's own experience." Newstex Blogs Tyranny of Numbers, retrieved from <https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:5XJT-3411-F03R-N2F3-00000-00&context=1519360> (Published November 17, 2019).

SAMA. 2020. "Annual Statistics." Saudi Arabian Monetary Authority, Riyadh, Saudi Arabia.

Saudi Aramco. 2018. Private Communication.

Saudi Aramco. 2024. "Saudi Aramco announces breakdown of shareholding post-allocation." Saudi Aramco. Available at: <https://www.aramco.com/en/news-media/news/2024/saudi-aramco-announces-breakdown-of-shareholding-post-allocation> (accessed April 20, 2025)

Saudi Aramco. 2025. "Retail fuels." Saudi Aramco. Available at: <https://www.aramco.com/en/what-we-do/energy-products/retail-fuels> (accessed April 20, 2025)

Saudi Green Initiative. 2025. "Proactive green initiatives for positive global impact." Saudi Green Initiative, Riyadh, Saudi Arabia. Available at: <https://www.sgi.gov.sa/saudi-global-climate-impact> (accessed April 20, 2025)

Saudi Vision 2030. 2016. "Saudi Vision 2030 Overview." Saudi Vision 2030. Available at: <https://www.vision2030.gov.sa/media/cofh1nmf/vision-2030-overview.pdf>

- Saudi Vision 2030. 2024. "Vision Realization Programs." Saudi Vision 2030. Available at: <https://www.vision2030.gov.sa/en/vision-2030/vrp/>
- Sayadi, Mohamad, Habib Soheyli Ahmadi, and Razieh Sadat Musavi Khaledi. 2023. "Evaluation of Barriers to Energy Subsidy Reform in Iran using the Fuzzy Analytical Hierarchy Process (FAHP) Method." *Iranian Energy Economics* 49(13): 111-146.
- Schaffitzel, Filip, Michael Jakob, Rafael Soria, Adrien Vogt-Schilb and Hauke Ward. 2020. "Can government transfers make energy subsidy reform socially acceptable? A case study on Ecuador." *Energy Policy* 137.
- SEC. 2019. "Annual Report 2018." Saudi Electricity Company, Riyadh, Saudi Arabia.
- SEEC. 2021a. "Industry Sector." Saudi Energy Efficiency Center, Riyadh, Saudi Arabia. Available at: <https://seec.gov.sa/en/energy-sectors/industry-sector/> (accessed Sep 28, 2021).
- SEEC. 2021b. Buildings sector." Saudi Energy Efficiency Center, Riyadh, Saudi Arabia. Available at: <https://seec.gov.sa/en/energy-sectors/buildings-sector/> (accessed Sep 28, 2021).
- Skaaning, Svend-Erik. 2020. "The Civil Liberty Dataset (CLD) Codebook." Available at: <https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/0TKJWX>
- SNA. 2008. "System of National Accounts 2008." World Bank. Washington D.C., USA. Available at: <http://documents.worldbank.org/curated/en/417501468164641001/System-of-national-accounts-2008>
- Söderbom, Måns, Francis Teal, Markus Eberhardt, Simon Quinn, and Andrew Zeitlin. 2015. *Empirical Development Economics*. First Edition. Routledge.
- SPA. 2017. "Ministry of energy and mineral resources clarifies new domestic pricing scheme for oil products." Translated from Arabic. Saudi Press Agency. Available at: <https://www.spa.gov.sa/1704319>. (Published December 31, 2017).
- SPA. 2024. "Public Transport Transformation is an Investment in Quality of Life, Environmental Sustainability, Railways Chief Says." Saudi Press Agency. Available at: <https://www.spa.gov.sa/en/N2215119>. (Published November 27, 2024).

StataCorp. 2019. "Stata: Release 16." Statistical Software. College Station, USA.

Steenblik, Ronald. 2003. "Subsidy measurement and classification: developing a common framework." Chapter in *Environmentally Harmful Subsidies: Policy Issues and Challenges*, published by the OECD.

Sullivan, Rory. 2022. "Kazakh government resigns amid fuel price protests." The Independent - Daily Edition, retrieved from: <https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:64G6-C8S1-F072-44F4-00000-00&context=1519360>. (Published January 06, 2022).

Taking, Anna. 2010. "Economics Watch: Making subsidy cuts more palatable." The Edge Malaysia, retrieved from: <https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:800C-4V71-2R97-019N-00000-00&context=1519360>. (Published July 19, 2010).

Taylor, Michael. 2020. "Energy Subsidies: Evolution in the Global Energy Transformation to 2050." IRENA, Abu Dhabi, United Arab Emirates.

The Associated Press. 1998. "Violence erupts in Indonesia as fuel and transport prices go up." The Associated Press, retrieved from: <https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:3SMF-TNJ0-007D-K275-00000-00&context=1519360> (published May 5, 1998).

The Associated Press. 2000. "Violent protests against fuel price hike in Indonesia." The Associated Press, retrieved from: <https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:41BB-4140-009F-R2RJ-00000-00&context=1519360>. (Published October 2, 2000).

The Daily Star. 2022. "Fuel prices cut by Tk 5 per litre." The Daily Star (Bangladesh), retrieved from: <https://www.thedailystar.net/environment/natural-resources/energy/news/fuel-prices-cut-tk-5-litre-3106031>. (Published August 29, 2022).

The Financial Express. 2022a. "Bangladesh considers fuel price revision." The Financial Express (Bangladesh), retrieved from: <https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:668B-WS41-JDKC-R4HW-00000-00&context=1519360>. (Published August 29, 2022).

The Financial Express. 2022b. "Tunisia hikes cooking gas, fuel prices in bid to cut subsidies." The Financial Express (Bangladesh), retrieved from: <https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:66DM-5821-JDKC-R173-00000-00&context=1519360>. (Published September 18, 2022).

The Hindustan Times. 2005. "Petrol, diesel price hiked, kerosene, LPG spared." The Hindustan Times, retrieved from: <https://www.proquest.com/newspapers/petrol-diesel-price-hiked-kerosene-lpg-spared/docview/469585222/se-2>. (Published September 06, 2005).

The Hindustan Times. 2016. "LPG price hiked by Rs 2; kerosene to add Rs 2.50 over 10 months." The Hindustan Times, retrieved from <https://www.proquest.com/newspapers/lpg-price-hiked-rs-2-kerosene-add-50-over-10/docview/1809077469/se-2>. (Published August 02, 2016).

The Saudi Gazette. 2020. "Saudi Arabia ups fuel prices, revision will now be monthly." The Saudi Gazette, retrieved from: <https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:5Y74-14V1-JDJN-62YN-00000-00&context=1519360>. (Published February 16, 2020).

U.S. Department of State. 2024. "Joint Statement Marking Three Years Since the Military Coup in Myanmar." Available at: <https://www.state.gov/joint-statement-marking-three-years-since-the-military-coup-in-myanmar/#:~:text=Three%20years%20ago%2C%20on%201,thousands%20jailed%2C%20tortured%20and%20killed>

Uberti, Luca J. 2022. "Interpreting logit models." *The Stata Journal* 22(1): 60-76.

UN Climate Change Conference. 2021. "COP26: The Glasgow Climate Pact." UN Climate Change Conference UK 2021. Available at: <https://ukcop26.org/wp-content/uploads/2021/11/COP26-Presidency-Outcomes-The-Climate-Pact.pdf>

UNDP. 2023. "Human Development Index." United Nations Development Programme. New York, USA. Available at: <https://hdr.undp.org/data-center/human-development-index#/indicies/HDI>

UNEP. 2003. "Energy subsidies: lessons learned in assessing their impact and designing policy reforms." UNEP/ETB/2003/1, United Nations Environment Programme, Nairobi, Kenya.

UNEP. 2008. "Reforming Energy Subsidies: Opportunities to contribute to the Climate Change Agenda." , United Nations Environment Programme. Available at: <https://wedocs.unep.org/20.500.11822/25941>.

Vagliasindi, Maria. 2013. "Implementing Energy Subsidy Reforms: Evidence from Developing Countries." *Directions in Development*, World Bank. Washington D.C., USA.

Valencia, Alexandra. 2021. "Ecuador to scrap monthly fuel price increases, establishes fixed price – Lasso." Reuters, retrieved from: <https://www.reuters.com/business/energy/ecuador-scrap-monthly-fuel-price-increases-establishes-fixed-price-lasso-2021-10-22/> (Published October 23, 2021).

Varian, Hal R. 1992. *Microeconomic Analysis*. Third Edition, W. W. Norton & Company, New York, USA.

Viktor, David. 2009. "The Politics of Fossil-Fuel Subsidies." Global Subsidies Initiative, International Institute for Sustainable Development, Geneva, Switzerland.

Vollgraaf, Rene. 2019. "Angola will only scrap subsidies when cash transfers are ready." Bloomberg, retrieved from <https://www.bloomberg.com/news/articles/2019-10-19/angola-will-only-scrap-subsidies-when-cash-transfers-are-ready>. (Published October 19, 2019).

Whitley, Shelagh and Laurie van der Burg. 2018. "Reforming Fossil Fuel Subsidies: The Art of the Possible." Chapter 3 in *The Politics of Fossil Fuel Subsidies and Their Reform*, edited by Jakob Skovgaard and Harro van Asselt. Cambridge University Press.

Widianto, Stanley. 2022. "Protests across Indonesia as anger mounts over fuel price increase." Reuters, retrieved from: <https://www.reuters.com/world/asia-pacific/rallies-expected-across-indonesia-anger-simmers-over-fuel-price-hike-2022-09-06/>. (Published September 06, 2022).

Wijayatunga, Priyantha D.C. and Rahula A. Attalage. 2002. "Analysis of household cooking energy demand and its environmental impact in Sri Lanka." *Energy Conversion and Management* 43(16): 2213-2223.

Wooldridge, Jeffrey M. 2010. *Econometric Analysis of Cross Section and Panel Data*. Second Edition, The MIT Press.

Wooldridge, Jeffrey N. 2013. *Introductory Econometrics: A Modern Approach*. South Western, Cengage Learning.

Woolley, John T. 2000. "Using Media-Based Data in Studies of Politics," *American Journal of Political Science* 44(1): 156-173.

World Bank. 2024a. "World Bank Open Data." Available at:  
<https://data.worldbank.org/>

World Bank, 2024b. "World Governance Indicators." Available at:  
<https://www.worldbank.org/en/publication/worldwide-governance-indicators/interactive-data-access>

World Socialist Web Site. 2022. "Street protests erupt across Bangladesh over fuel price hikes." World Socialist Web Site, retrieved from:  
<https://www.wsws.org/en/articles/2022/08/15/tyeo-a15.html> (Published August 14, 2022).

WTO. 2005. "Report of the working party on the accession of the Kingdom of Saudi Arabia to the World Trade Organization." World Trade Organization, Geneva, Switzerland.

WTO. 1994. "Agreement on Subsidies and Countervailing Measures." World Trade Organization, Geneva, Switzerland.

WTO. 2005. "Report of the Working Party on the Accession of the Kingdom of Saudi Arabia to the World Trade Organization." WT/ACC/SAU/61. World Trade Organization, Geneva, Switzerland.

WTO. 2006. "World Trade Report 2006." World Trade Organization, Geneva, Switzerland. Available at:  
[https://www.wto.org/english/res\\_e/booksp\\_e/anrep\\_e/world\\_trade\\_report06\\_e.pdf](https://www.wto.org/english/res_e/booksp_e/anrep_e/world_trade_report06_e.pdf)

WTO. 2024. "Members and Observers." World Trade Organization, Geneva, Switzerland. Available at:  
[https://www.wto.org/english/thewto\\_e/whatis\\_e/tif\\_e/org6\\_e.htm#:~:text=164%20members%20since%2029%20July,trade%20policy%20reviews%2C%20and%20notifications.](https://www.wto.org/english/thewto_e/whatis_e/tif_e/org6_e.htm#:~:text=164%20members%20since%2029%20July,trade%20policy%20reviews%2C%20and%20notifications.)

Xinhua General News Service. 2003. "Protests against price hike spread over Indonesia." Xinhua General News Service, retrieved from: <https://advance.lexis.com/api/document?collection=news&id=urn:contentItem:47N3-VS90-00RC-93X3-00000-00&context=1519360>. (Published January 9, 2003).

Zaldumbide, Jaime. 2020. "Oil and gas regulation in Ecuador: overview." Thomson Reuters Practical Law. Available at: [https://uk.practicallaw.thomsonreuters.com/w-028-6002?transitionType=Default&contextData=\(sc.Default\)&firstPage=true](https://uk.practicallaw.thomsonreuters.com/w-028-6002?transitionType=Default&contextData=(sc.Default)&firstPage=true)

## Author Contribution Statement

This thesis brings together all my PhD research, encompassing four journal papers. Two journal papers have been published, and I expect the other two papers to be published in 2025. I am lead author of all four journal papers. The contributions of my journal paper co-authors have been noted in each of the research paper declaration forms, and they are also detailed again in this section, along with acknowledgements of other researchers that influenced my research.

Chapter 2 contains all the energy demand modelling work from the journal paper titled “Modeling Final Energy Demand and the Impacts of Energy Price Reform in Saudi Arabia,” which was published in *Energy Economics*. As lead author, I conceptualized this work, building on past research I had conducted with my former director at KAPSARC, Lester Hunt. After conceptualizing the study, I collected the data, conducted the literature review, applied the econometric methodology, ran the time series regressions, ran impact analyses, visualized the data, wrote the original draft, and reviewed and edited the final manuscript. My supervisors, Paolo Agnolucci and Paul Ekins, supervised my work and guided me on the methodology and regression results. They also reviewed and edited the final manuscript. Vincenzo De Lipsis, who was at UCL when I started conducting this research, contributed intellectually to my supervisory meetings during the first year of my PhD. He also reviewed and edited the final manuscript. Mohamad Hejazi, Muhammad Javid, Jeyhun Mikayilov, Axel Pierru, Alvaro Calzadilla Rivera, and Neil Strachan provided feedback on this research.

Chapter 3 contains content from two published journal papers. First, it includes the economic and environmental impact analysis from the journal paper titled “Modeling final energy demand and the impacts of energy price reform in Saudi Arabia,” which was published in *Energy Economics*. As discussed above, I am the lead author of this journal paper, and the direct and indirect contributions of others to this paper have already been noted. Second, Chapter 3 contains the fiscal analysis of energy subsidies from the journal paper titled “Revisiting Energy Subsidy Calculations: A Focus on Saudi Arabia,” which was published in *The Energy Journal*. As lead author, I conceptualized this work, starting with the goal of addressing a concern that policymakers have in Saudi Arabia regarding the value of a barrel of oil. My

KAPSARC PhD supervisor, Axel Pierru, provided guidance through his previous research into this topic, which also inspired my work. I conceptualized the study, conducted the literature review, collected data, co-developed a novel methodology for measuring the fiscal impacts of energy subsidy reform, ran the calculations, visualized the data, co-wrote the original draft, and reviewed and edited the final manuscript. The novel methodology was co-developed with my colleague at KAPSARC, Walid Matar. Through a series of conversations, we co-developed this method and wrote the original draft together. In Chapter 3, I have taken this methodology that we co-developed and applied it more comprehensively, adding further nuance while applying it to energy subsidies on oil products. My comprehensive application of this methodology in my thesis is entirely new and was not presented in the published journal paper. However, since Walid and I wrote the methodology section of the journal paper together, I rewrote that section for Chapter 3 of my thesis. My supervisors, Paolo Agnolucci and Paul Ekins, supervised my work and reviewed and edited the final manuscript. Rami Shabaneh, Vincenzo De Lipsis, Kaushik Deb, Alvaro Calzadilla Rivera, and Neil Strachan provided feedback on this research.

Chapter 4 contains all my work on the lessons learned from past energy subsidy reforms from the journal paper titled “Lessons from an International Review of Successful and Unsuccessful Energy Subsidy Reforms,” which is undergoing peer review in the *Energy Journal*. As lead author, I conceptualized this study under the direction of my supervisors, building on the discussions I had with my PhD Upgrade committee (specifically, Alvaro Calzadilla Rivera and Neil Strachan). For this study, I collected data (the most time-consuming part), conducted the literature review, analyzed news content for insights, visualized the data, wrote the original draft, and reviewed and edited the final manuscript. My supervisors, Paolo Agnolucci and Paul Ekins, helped me conceptualize this study and supervised me throughout it. They also reviewed and edited the final manuscript. Lama Yaseen provided valuable comments throughout this research and supported data curation. Fateh Belaid, Mohamad Hejazi, Axel Pierru, and Fahad Alajlan provided feedback on this research.

Chapter 5 contains all my work on the determinants of successful energy subsidy reforms from the journal paper titled “The Determinants of Successful Energy

Subsidy Reforms: A Logistic Regression Analysis,” which I plan to submit to *Energy Policy*. As lead author, I conceptualized this study under the direction of my supervisors, building on the discussions I had with my PhD Upgrade committee (specifically, Alvaro Calzadilla Rivera and Neil Strachan). I also leveraged the data I collected for Chapter 4. In addition, I collected data from other sources to run the logistic regressions, which was done with the direct support of Lama Yaseen, a colleague at KAPSARC. Lama Yaseen also helped me validate my dataset and conducted data curation. After data collection, I performed the literature review, ran the logistic regressions, visualized the data, wrote the original draft, and reviewed and edited the final manuscript. My supervisors, Paolo Agnolucci and Paul Ekins, helped me conceptualize this study and supervised me throughout my research. They, along with Lama Yaseen, also reviewed and edited the final manuscript. Rubal Dua, Fateh Belaid, Mohamad Hejazi, Axel Pierru, and Fahad Alajlan provided feedback on this research.

# Appendices

## Appendix A. Unit Root and Cointegration Tests

In line with the cointegration method, stationarity and cointegration tests were conducted for the variables and energy demand equations presented in Chapter 2. The results from the Augmented Dickey-Fuller unit root tests are shown in Table 39 for all the variables in each energy demand equation. Table 39 demonstrates that all variables are integrated of order one at the 10% statistical significance level, with cooling degree days being the only exception, as the variable appears to be trend-stationary.

The results from Pesaran's cointegration bounds test using the autoregressive distributed lag equation are shown in Table 40. When excluding the stochastic trend, the results show cointegration for all equations, with only the industrial diesel equation having an indeterminate result. (Its F-statistic falls between both bounds.) However, when including the UEDT that was estimated through the STSM as a fixed regressor in the bounds test, cointegration is found for all equations.

**Table 39** The *t*-statistics from the Augmented Dickey-Fuller unit root tests. The optimal lag is chosen based on the Schwarz information criterion. The \*, \*\*, and \*\*\* denote statistical significance at the 10%, 5%, and 1% levels, respectively. Abbreviations: *e* = energy product demand; *p* = real energy price; *y* = real economic activity; *rgdp* = real gross domestic product; *rmva* = real manufacturing value added; *fp* = fertilizer production; *rcpx* = real chemical and plastic exports; *LPG* = liquified petroleum gas.

| Model                                 | Variable (in logs) | Level    | First Difference |
|---------------------------------------|--------------------|----------|------------------|
| Transport gasoline                    | <i>e</i>           | -2.66    | -4.37***         |
|                                       | <i>p</i>           | -1.54    | -3.67**          |
|                                       | <i>y (rgdp)</i>    | -2.54    | -8.24***         |
| Transport diesel                      | <i>e</i>           | -2.53    | -5.84***         |
|                                       | <i>p</i>           | -1.69    | -5.36***         |
|                                       | <i>y (rgdp)</i>    | -2.54    | -8.24***         |
| Transport kerosene                    | <i>e</i>           | -1.90    | -5.09***         |
|                                       | <i>p</i>           | -1.77    | -5.46***         |
|                                       | <i>y (rgdp)</i>    | -2.54    | -8.24***         |
| Residential LPG                       | <i>e</i>           | -1.18    | -7.45***         |
|                                       | <i>p</i>           | -1.54    | -5.59***         |
|                                       | <i>y (rgdp)</i>    | -2.54    | -8.24***         |
| Residential electricity               | <i>e</i>           | 0.13     | -4.44***         |
|                                       | <i>p</i>           | -1.75    | -2.94*           |
|                                       | <i>y (rgdp)</i>    | -2.54    | -8.24***         |
|                                       | <i>cdd</i>         | -4.96*** | -9.34***         |
| Residential total energy              | <i>e</i>           | 0.43     | -4.35***         |
|                                       | <i>p</i>           | -1.97    | -3.24**          |
|                                       | <i>y (rgdp)</i>    | -2.54    | -8.24***         |
|                                       | <i>cdd</i>         | -4.96*** | -9.34***         |
| Commercial & governmental electricity | <i>e</i>           | -2.62    | -9.82***         |
|                                       | <i>p</i>           | -2.71    | -7.58***         |
|                                       | <i>y (rgdp)</i>    | -2.54    | -8.24***         |
|                                       | <i>cdd</i>         | -4.96*** | -9.34***         |
| Industrial natural gas                | <i>e</i>           | -2.19    | -7.02***         |
|                                       | <i>p</i>           | -1.69    | -4.93***         |
|                                       | <i>y (rmva)</i>    | -1.74    | -2.94*           |
| Industrial diesel                     | <i>e</i>           | -2.01    | -5.40***         |
|                                       | <i>p</i>           | -1.88    | -4.80***         |
|                                       | <i>y (rmva)</i>    | -1.74    | -2.94*           |
| Industrial electricity                | <i>e</i>           | -1.68    | -4.96***         |
|                                       | <i>p</i>           | -1.82    | -5.12***         |
|                                       | <i>y (rmva)</i>    | -1.74    | -2.94*           |

|                           |                 |       |          |
|---------------------------|-----------------|-------|----------|
| Industrial total          | <b>e</b>        | -1.56 | -6.83*** |
|                           | <b>p</b>        | -2.14 | -6.38*** |
|                           | <b>y (rmva)</b> | -1.74 | -2.94*   |
|                           | <b>SF</b>       | -3.16 | -5.77*** |
| Feedstock methane         | <b>e</b>        | -0.66 | -6.05*** |
|                           | <b>p</b>        | -1.69 | -4.93*** |
|                           | <b>y (fp)</b>   | -3.10 | -5.01*** |
| Feedstock ethane          | <b>e</b>        | -2.74 | -3.86**  |
|                           | <b>p</b>        | -1.66 | -5.12*** |
|                           | <b>y (rcpx)</b> | -3.12 | -4.07**  |
| Feedstock LPG and naphtha | <b>e</b>        | -2.30 | -5.13*** |
|                           | <b>p</b>        | -1.33 | -4.40**  |
|                           | <b>y (rcpx)</b> | -2.60 | -3.96**  |
| Feedstock total           | <b>e</b>        | -2.64 | -6.22*** |
|                           | <b>p</b>        | -1.43 | -5.06*** |
|                           | <b>y (rmva)</b> | -1.74 | -2.94*   |

**Table 40** The F-statistics from the F-Bounds test for cointegration, presented alongside the bounds at the 10% statistical significance level. Abbreviations: e = energy product demand; p = real energy price; y = real economic activity; rgdp = real gross domestic product; rmva = real manufacturing value added; fp = fertilizer production; rcpx = real chemical and plastic exports; LPG = liquified petroleum gas; UEDT = underlying energy demand trend.

| Model                                 | Dynamic Regressors         | Fixed Regressors | F-Statistic Value | I(0) @ 10% | I(1) @ 10% |
|---------------------------------------|----------------------------|------------------|-------------------|------------|------------|
| Transport gasoline                    | <b>e, p, y (rgdp)</b>      | None             | 13.57653          | 2.63       | 3.35       |
|                                       |                            | UEDT             | 6.54E+20          | 2.63       | 3.35       |
| Transport diesel                      | <b>e, p, y (rgdp)</b>      | None             | 3.850115          | 2.63       | 3.35       |
|                                       |                            | UEDT             | 14021.74          | 2.63       | 3.35       |
| Transport kerosene                    | <b>e, p, y (rgdp)</b>      | None             | 5.875290          | 2.63       | 3.35       |
|                                       |                            | UEDT             | 209.0507          | 2.63       | 3.35       |
| Residential LPG                       | <b>e, p, y (rgdp)</b>      | None             | 4.160820          | 2.63       | 3.35       |
|                                       |                            | UEDT             | 21387.38          | 2.63       | 3.35       |
| Residential electricity               | <b>e, p, y (rgdp), cdd</b> | None             | 51.26452          | 2.63       | 3.35       |
|                                       |                            | UEDT             | 1.41E+22          | 2.63       | 3.35       |
| Residential total energy              | <b>e, p, y (rgdp)</b>      | None             | 10.09826          | 2.63       | 3.35       |
|                                       |                            | UEDT             | 3.14E+22          | 2.63       | 3.35       |
| Commercial & governmental electricity | <b>e, p, y (rgdp)</b>      | None             | 9.829673          | 2.37       | 3.20       |
|                                       |                            | UEDT             | 46544.82          | 2.37       | 3.20       |
| Industrial natural gas                | <b>e, p, y (rmva)</b>      | None             | 6.640870          | 2.63       | 3.35       |
|                                       |                            | UEDT             | 330.0522          | 2.63       | 3.35       |
| Industrial diesel                     | <b>e, p, y (rmva)</b>      | None             | 3.007450          | 2.63       | 3.35       |
|                                       |                            | UEDT             | 269.3944          | 2.63       | 3.35       |
| Industrial electricity                | <b>e, p, y (rmva)</b>      | None             | 6.301203          | 2.63       | 3.35       |
|                                       |                            | UEDT             | 68.92720          | 2.63       | 3.35       |
| Industrial total                      | <b>e, p, y (rmva), SF</b>  | None             | 5.049221          | 2.37       | 3.20       |
|                                       |                            | UEDT             | 1067.122          | 2.37       | 3.20       |

|                           |                       |      |          |      |      |
|---------------------------|-----------------------|------|----------|------|------|
| Feedstock methane         | <b>e, p, y (fp)</b>   | None | 13.77329 | 2.63 | 3.35 |
|                           |                       | UEDT | 2.79E+23 | 2.63 | 3.35 |
| Feedstock ethane          | <b>e, p, y (rcpx)</b> | None | 6.223268 | 2.63 | 3.35 |
|                           |                       | UEDT | 9.449076 | 2.63 | 3.35 |
| Feedstock LPG and naphtha | <b>e, p, y (rcpx)</b> | None | 5.501200 | 2.63 | 3.35 |
|                           |                       | UEDT | 21.78342 | 2.63 | 3.35 |
| Feedstock total           | <b>e, p, y (rmva)</b> | None | 11.96934 | 2.63 | 3.35 |
|                           |                       | UEDT | 64.70276 | 2.63 | 3.35 |

## Appendix B: Point Elasticities Versus Arc Elasticities

Most estimates of price elasticities in the literature are obtained from studies that econometrically estimate energy demand equations using log-log models. These studies, which generally assume a constant price elasticity function, provide estimates of point elasticities. For very small changes in energy prices, point and arc elasticities are effectively equal, but they do diverge when price changes become large. Arc elasticities are thus preferably used when price changes are small (Allen and Lerner, 1934). However, even with large price changes, the arc elasticity can be calculated given a point elasticity estimate from the literature.

In Chapter 3, I formulated the price elasticity for domestic energy demand as follows, using a discrete arc elasticity formulation:

$$\varepsilon^{arc} = \frac{(Q_a - Q_b)}{Q_b} \cdot \frac{P_b}{(P_a - P_b)} \quad [B1]$$

where  $\varepsilon^{arc}$  is the arc elasticity,  $Q_a$  the demand for energy after the price change,  $Q_b$  the demand before the price change,  $P_a$  the new price after the change, and  $P_b$  the price before the change.

In contrast, most econometric studies of energy demand assume the following constant elasticity demand equation, which was also used in Chapter 2 of this thesis:

$$Q = AP^{\varepsilon^{pnt}} \quad [B2]$$

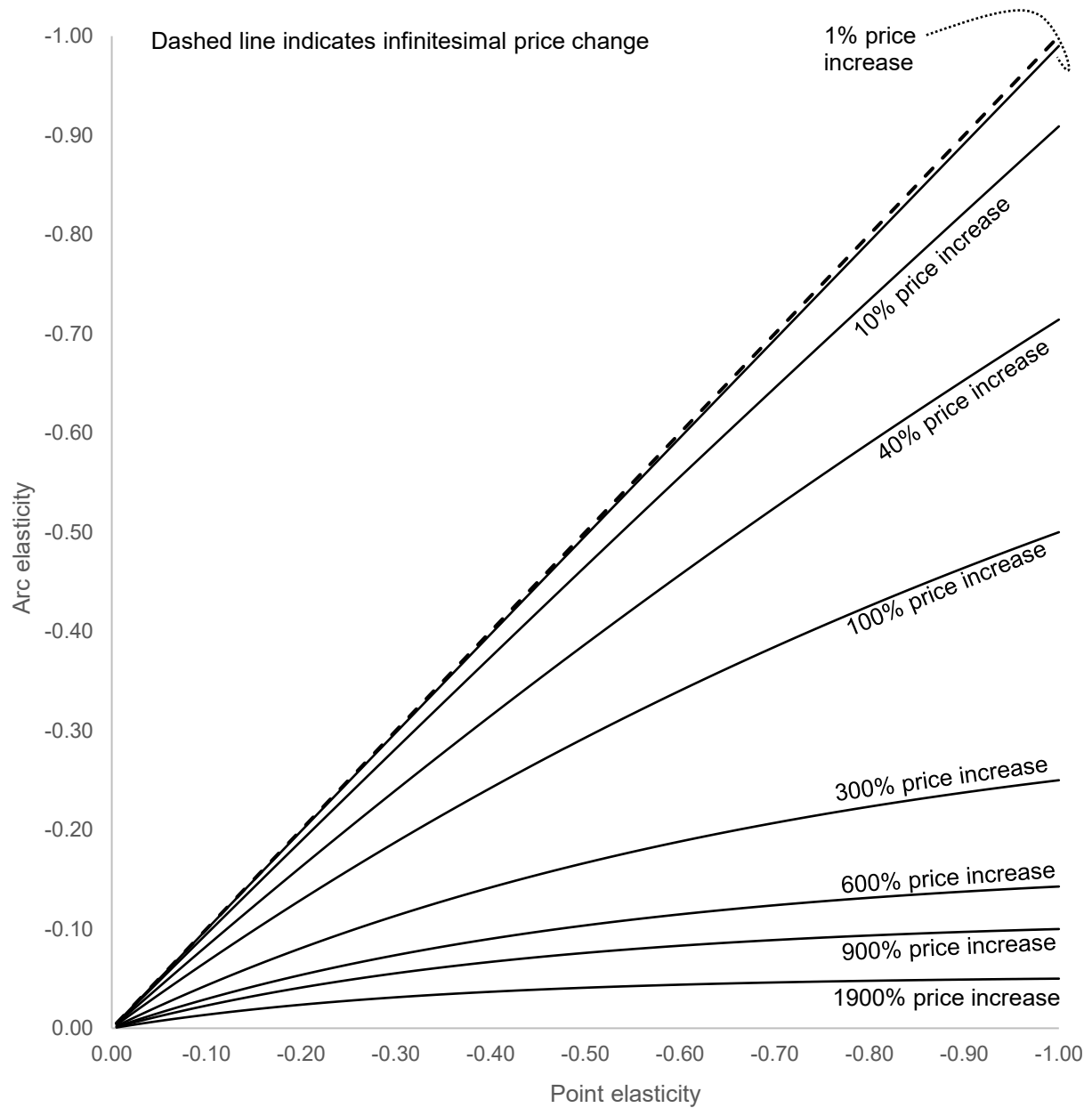
where  $Q$  is the quantity of energy demanded,  $P$  is the domestic energy price, and  $A$  is the scale parameter, while  $\varepsilon^{pnt}$  is the point elasticity.

By substituting Equation [B2] into Equation [B1], it is possible to demonstrate that:

$$\varepsilon^{arc} = \frac{P_1(P_2^{\varepsilon^{pnt}} - P_1^{\varepsilon^{pnt}})}{P_1^{\varepsilon^{pnt}}(P_2 - P_1)} \quad [B3]$$

Equation [B3] illustrates how the arc elasticity can be calculated from a point elasticity estimate. It also shows that the deviation between the arc and point elasticities depends on the size of the price increase (see Figure 21). For infinitesimally small price changes, the arc and point elasticities are equivalent, as illustrated by the 45-degree line through Figure 21. With a 1% price increase, the arc elasticity remains almost equal to the point elasticity, but the two begin to diverge for price increases of 10% and above, with the gap increasing as the point elasticity

grows larger. The divergence between the two elasticities becomes substantial at extremely large price changes.



**Figure 21** The relationship between the arc and point price elasticities for a range of price increases.