Reducing CO_2 Emissions from Residential Energy Use

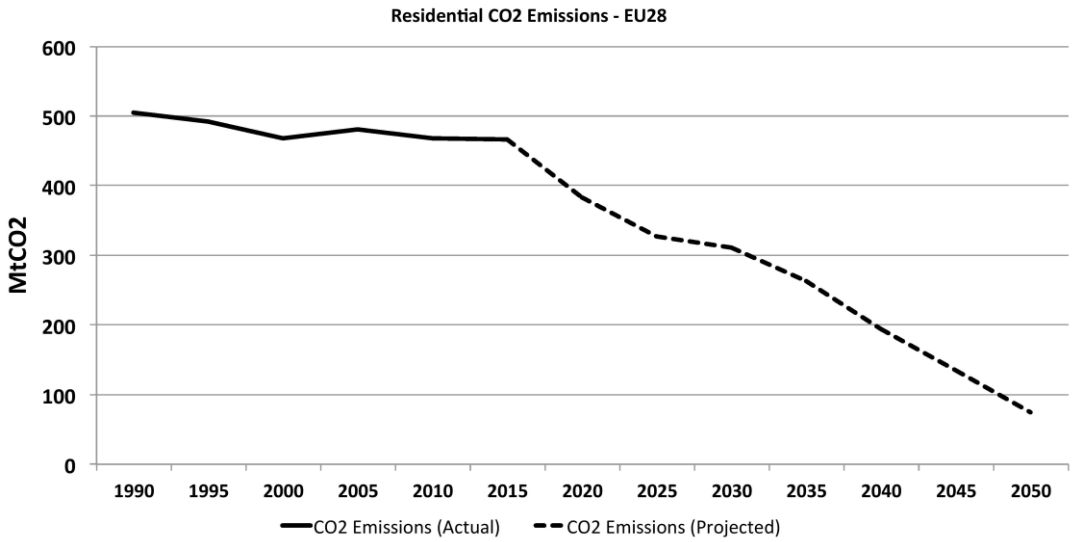
Abstract

To achieve EU GHG emissions of 80-95% below 1990 levels by 2050, CO_2 emissions from residential energy consumption must be substantially reduced. Recognition of this has led to the introduction of a range of policy instruments at both EU and Member State level. This paper examines these policies, for the EU the UK, first by grouping them into three 'pillars of policy' – standards & engagement, markets & pricing, and strategic investment (each of which focus on different 'domains of change' embodying different economic processes) - and then by assessing the strengths and weaknesses of each pillar in terms of instrument coverage and effectiveness. The paper finds strengths and weaknesses common to both UK and EU policy landscapes, including a comprehensive but broadly ineffective standards & engagement pillar of policy, and an ineffective markets & pricing landscape (including effective subsidisation of energy consumption in the UK, permitted by the EU), with poor coverage. The strategic investment landscape is found (until recently) to be substantially stronger in the UK compared to EU instruments and requirements. Priority reform actions are also proposed to address the weaknesses identified. The paper also offers discussion of recent policy developments in the UK.

Keywords: Climate Policy, Energy Efficiency, Energy Policy, Policy Formation, Policy Measures

Introduction

This paper is concerned with CO_2 emissions from energy use by the EU and UK residential sector[1]. This includes both regulated energy, defined as energy use by a building, including heating (space and water), ventilation and air conditioning (HVAC) and lighting), and non-regulated (household) energy, defined as energy use in a building, particularly by appliances and equipment bought by the occupier. Direct CO_2 emissions alone from the residential sector accounted for 11% of total CO_2 emissions from the EU28 in 2012 (EEA, 2015a), with upstream emissions associated with residential electricity consumption adding significantly to this. If the stated goal of a reduction in EU GHG emissions of 80-95% below 1990 levels by 2050 is to be achieved (EC, 2011), the residential sector must therefore decarbonise very substantially over the coming decades.



< ***Figure 1 -*** *Actual and projected CO_2 emissions from the residential sector 1990-2050 - EU28*>

Figure 1 illustrates historic residential CO_2 emissions from the EU28, and projected requirements to 2050 based on the Commission's Energy Roadmap 2050 ('Diversified Supply Technologies' Scenario), which seeks to map out the contribution required by each sector if the overarching GHG targets, described above, are to be achieved (EC, 2011). This scenario envisages an 85% reduction in direct residential CO_2 emissions from 1990 levels by 2050. Between 1990 and 2010, such emissions reduced by an average of 1.8% annually. To achieve the 2050 target, this value must increase to 4.4% from 2010 onwards[2]. To compound this already substantial challenge, the number of households is projected to increase by around 25% over this time (IEA, 2012).

However, EEA (2015b) projects that direct CO_2 emissions from buildings across the EU will reduce by an annual average of around 1.3% between 2010 and 2030 under existing measures, and around 1.5% with the addition of 'planned measures'. Whilst this projection pertains to all buildings, as the residential sector currently accounts for around 70% of direct emissions from all buildings (EEA, 2015a), it is reasonable to conclude that the rate for the residential sector only would not deviate substantially from this aggregate projection. In addition, EC (2011), along with much of the wider literature, foresee such decarbonisation to be achieved in large part through electrification of key energy services (particularly space heating). As such, it is important that CO_2 emissions from electricity generation also decrease significantly over time (over 95% by 2050, from 1990 levels).

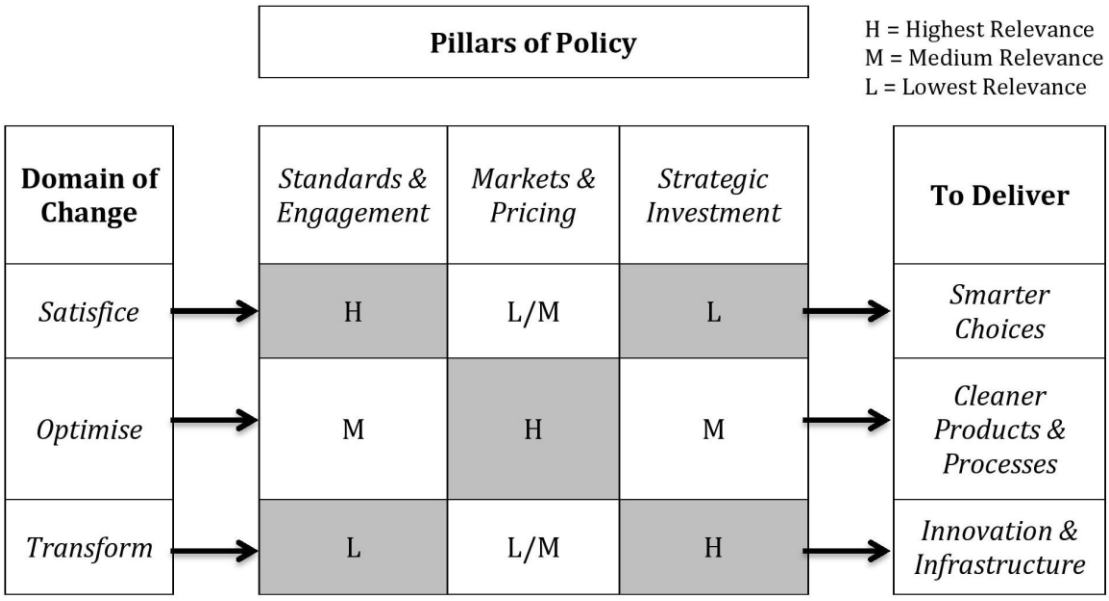
It is clear that an effective, well-coordinated and strengthened policy instrument mix must be in place, both at the EU level and within Member States, to drive such an ambitious transformation. This paper will first present, in Section 1, a conceptual framework regarding the three 'domains of change' and related 'pillars of policy', developed by Grubb, Hourcade and Neuhoff (2014), that are required to deliver a low-carbon transition. Section 2 presents the methodology for the assessment undertaken in Sections 3 and 4, the latter of which maps the existing climate and energy policy instrument mix related to the residential building sector, first at the EU level, and then in a key Member State (the United Kingdom), onto this conceptual framework. Key strengths and weaknesses will be identified in each instrument mix against this framing, and suggestions for improvement put forward. Section 5 concludes.

The Three Pillars of Policy

The need for a combination of policy instruments in order to address the multiple market failures that lead to the excessive generation of environmental pollutants has long been recognised in the literature (e.g. Lipsey and Lancaster, 1956). A number of different environmental policy instrument typologies have also been developed. For example, Jordan et al. (2003) group instruments under four generic headings: market/incentive-based (also called economic) instruments; classic regulation instruments; voluntary (also called negotiated) agreements; and information/education-based instruments. The policy instrument framework of OECD (2008) consists of direct environmental regulation, environmentally related taxes, tradable permits, public financial

support for environmental goods and services, instruments to promote technological development, and information-based and voluntary approaches. Wurzel, Zito and Jordan (2013, p.26) provide a recent overview of policy instrument typologies, from which it is clear that no single typology can be considered 'correct'; the choice of which to use should depend on the purpose in hand.

Regarding climate policy specifically, the landmark Stern Review on the Economics of Climate Change considered that a policy framework for CO_2 abatement should have three elements: carbon pricing, technology policy and the removal of barriers to behaviour change (Stern, 2006). For the purposes of this paper, this is an attractive typology because each kind of instrument reflects a different kind of barrier to the efficient market implementation of energy efficiency and low-carbon measures: characteristics of human behaviour that do not accord with economic rationality, negative externalities from energy use that cause energy efficiency and low-carbon technologies and behaviours to be undervalued, and positive externalities from innovation that prevent new energy efficient and low-carbon technologies from being developed. Recently, Grubb et al. (2014) have developed the three-fold Stern categorisation into a new framework to identify and analyse the policy elements that are likely to be required to successfully achieve a low-carbon transition. This framework, adapted for use in this paper, is illustrated in Figure 2



<***Figure 2 -*** *Three 'Domains of Change' and 'Pillars of Policy' (Adapted from Grubb et al., 2014*)>

Figure 2 shows three 'domains of change' and corresponding 'pillars of policy' for tackling CO_2 (and other GHG) emissions. Each domain of change reflects a distinct sphere of economic decision-making and development. The first, 'satisficing', draws on the insights from behavioural and organisational economics. Evidence from these fields demonstrates that individuals (and organisations) are not always 'rational optimisers'; they do not always respond to incentives to maximise their economic welfare over time. Four broad insights that produce this conclusion may be distilled. The first is that individuals are subject to 'bounded rationality', where decisions are constrained by cognitive processes and available information (which produces 'satisficing' behaviour, whereby individuals adopt behaviour that leads to outcomes that meet a threshold of satisfaction, rather than the economically optimal outcome) (Simon, 1956). The second insight is that individuals tend to have hyperbolic discount

rates, meaning that individuals do not discount the value of future costs and benefits at a consistent rate of over time. Such a discount rate is 'present-biased', meaning that the present value of long-term costs and benefits is much lower than the discount rate commonly used in economic models, which discounts future costs and benefits at a constant rate over time (Laibson, 1997). The third insight is that individuals tend to practice 'mental (or psychological) accounting', evaluating differently the utility received from different means of expenditure (e.g. via cash or credit card) (Morewedge, Holtzman and Epley, 2007). The fourth insight is that under uncertainty, individuals tend to rely for decision-making on heuristics, including 'rules of thumb', 'anchoring' (cognitive bias in future judgements based on the first piece of information provided), and the 'availability' of information in terms of the ease with which it is recalled (Kahneman, Slovic and Tversky, 1982).

The economically sub-optimal outcomes that result from these behavioural influences on decision-making may be addressed by policies that seek to produce 'smarter choices', either as default (e.g. through minimum standards), or through encouraging positive active choices (e.g. through engagement, and the provision of information). Such instruments form the standards & engagement pillar of policy in Grubb et al.'s framework (Grubb et al, 2014).

The second domain, 'optimising', draws upon the theories and assumptions of neoclassical and welfare economics. These schools of thought hold that individuals and organisations seek to maximise their welfare (utility) over time in response to economic incentives, with rational foresight and stable

preferences and technological options. Where markets are functioning perfectly, this results in an optimal 'general equilibrium' state for economic systems, in which private and social welfare is aligned and maximised from the most efficient use of a fixed set of resources. However, it is acknowledged that private and social incentives and welfare may be misaligned, or resources used inefficiently, due to the presence of market (and institutional) failures. A key example is (positive and negative) market externalities, where the socialised economic cost (or benefit) of an action is not internalised (i.e. priced in) to the private cost (or benefit). In the context of this paper, the predominant example is the market externality of CO_2 emissions. The economically sub-optimal outcomes that result from such situations may be addressed by policies that alter the economic calculus of actors, particularly pricing instruments (e.g. carbon pricing), to make 'cleaner products & processes' the economically rational choice. Instruments that alter the structure of the market are also important. Together, these form the markets & pricing pillar of policy (Grubb et al, 2014).

The third and final domain, 'transformation', draws upon the insights of evolutionary and institutional economics. The studies under these broad fields (and particularly the former) emphasise how technological and economic systems evolve over time, as a result of a dynamic interaction between historic developments, the direction of innovation, inherited infrastructure, and the nature of societal norms, values and institutions (Grubb et al, 2014; Norgaard, 2010). Institutional economics, as its name suggests, focuses specifically on the role of institutions ('including the state, political parties, courts, unions, firms, churches, and the like … [with their] rules, regulations, customs, common

practices and laws that regulate the actions of individuals and concerns' (Rutherford 1983, p.723)), in setting the 'rules of the game', including long-term direction and expectations. Economic and technological systems exhibit 'path dependency' and 'lock-in' arising from earlier decision-making, particularly in terms of the nature and availability of infrastructure, which to some extent at least determine future possibilities (Grubb et al. 2014, p.312). Private investment is likely to be constrained according to this dependency and lock-in. Without change at the institutional level, particularly through interventions by the public sector, with its unique role in seeking to maximise societal welfare through policy, law and the use of public funds, will tend towards paradigmatic transitions (such as decarbonisation) are difficult or impossible to achieve. A 'strategic investment' pillar of policy, which looks beyond short-term returns to invest in ways that support the evolution of more efficient and low-carbon technologies and systems (such as renewable energy), to produce appropriate 'innovation & infrastructure', is therefore required.

Each of the three domains and policy pillars, whilst presented as conceptually distinct, interact through numerous channels. As Figure 2 illustrates, whilst the impact is strongest in one, each of the pillars of policy have at least some influence on all three domains of change. Because household energy use exhibits characteristics of all domains, for an effective approach to decarbonisation policies from each of the three pillars need to be applied in a *policy mix*, which is an increasingly advocated approach to environmental policy more generally (OECD 2007). Grubb et al., 2014 consider all three domains, and by extension all

three pillars of policy, are of largely equal importance in delivering a low carbon energy system and economy (Grubb et al., 2014).

Methodology

Under the following two sections, Table 1 and Table 2 assign the key EU and UK-level instruments in the climate and energy policy landscape, as related to the residential building sector, to each of the three pillars of policy in Grubb et al.'s (2014) categorisation (standards & engagement, markets & pricing and strategic investment). The instruments selected are all those that explicitly seek to impact residential energy consumption, CO_2 emissions from residential energy consumption (including direct emissions from households, those from upstream electricity generation, and emission reduction through households' own generation from renewables), and those that directly enable the control of energy use and CO_2 emissions (e.g. requirements for the installation of smart meters). Requirements for the use of usually unspecified overarching strategies and plans, for example, are excluded from the analysis, as are instruments that support technological development but not deployment (e.g. funding for basic research). Table 1 and Table 2 also act as a 'list of abbreviations' for the text that follows. Whilst Table 2 also summarises the results of evaluations of the instruments listed for the UK, such information is not provided in Table 1 for the EU as comprehensive *ex-post* evaluations are not commonly available (and actual implementation for many instruments often varies substantially across Member States).

Each section proceeds to highlight the key strengths and weaknesses of the associated policy mix, based on an assessment of instrument coverage within each pillar of policy across sources of energy consumption and CO_2 emissions, and the effectiveness of the instruments in each pillar in achieving their objectives (either stated targets, or in terms of their stated purpose or theoretical justification). Such an assessment is made based on a review of the scientific literature and official evaluation reports, and where such literature is not available, by recourse to theoretical considerations. In the absence of full evaluations, these assessments inevitably have a subjective element in their characterisation of 'strengths' and 'weaknesses'. Each section then concludes with proposals for suggestions for priority reforms that may be introduced to correct the key weaknesses identified

The Policy Landscape - European Union

<Table 1 – Policy Landscapes across the 'Three Pillars' – European Union>

Type and Name of Intervention	Description of Intervention
Standards & Engagement	
Energy Performance of Buildings Directive (EPBD) (2010/31/EC)	- Member States must set cost-effective **minimum energy performance standards** (MEPS) (*Article 4*). - Any building sold or rented to a new tenant must be issues with an **Energy Performance Certificate** (EPC), illustrating energy performance data, reference values (such as minimum performance requirements), recommendations for cost-effective improvement options, and information on where to find further information (*Article 11*).
Energy Labelling Directive (ELD) (2010/30/EU)	- Energy-using products and energy-related products (those which do not consume, but impact the consumption of energy) are subject to **energy efficiency labelling.** Products must be subject to a Delegated Act before they are covered by this Directive.
Ecodesign Directive (2009/125/EC)	- Energy-using products and energy-related products (described above) are subject to **minimum environmental performance standards** (usually related to in-use energy consumption). Products must be subject to an Implementing Measure before they are subject to this Directive.
Energy Efficiency Directive (EED) (2012/27/EU)	- Member States must introduce **Energy Efficiency Obligation Schemes** (EEOS) for energy distributors and supplies to achieve annual savings of 1.5% total average energy sales by volume over 2009-2012, each year over the period 2014-2020 (*Article 7*). - '**Smart' meters must be provided** when a unit is replaced or a new connection is made, when technically feasible and cost-effective (*Article 9*). - If consumers do not have smart meters, **mandatory billing information** must contain (a) data based on actual consumption and information, such as daily consumption profiles, be made available free of charge (*Article 10*), (b) comparisons with average or benchmarked consumption, and (c) details on where to receive information on energy efficiency. - Member States must implement programmes to raise awareness of the benefits and availability of **energy audits** amongst households (*Article 8*). - Other **consumer information and empowerment programmes** to promote energy efficiency amongst small energy consumers (including domestic consumers). This may include fiscal incentives and grants. - **Qualification, accreditation and certification schemes** must be provided to providers of energy services, audits and

	installers of energy-efficiency elements, in Member States where technical competence, objectivity and reliability is insufficient (*Article 16*) - **Information and training** on energy efficiency mechanisms and financial and legal frameworks must also be provided to all relevant market actors (inc. consumers, builders, architects, auditors, etc.) (*Article 17*).
Third Energy Package – Electricity (D2009/72/EC)	- **80% of electricity consumers** (across all sectors) must be **fitted with smart meters by 2020** in each Member State, where cost-effectiveness is assessed positively (*Annex I*)
Renewable Energy Directive (RED) (2009/28/EC)	- The presence of renewable energy support schemes **must be publicised through awareness raising and training**, including to consumers, builders and architects (*Article 14*). - **Qualification and certification schemes must be made available** for installers of small-scale biomass boilers and stoves, solar photovoltaic and solar thermal systems, shallow geothermal systems and heat pumps (*Article 14*).
Markets & Pricing	
EU ETS (2009/29/EC)	- The EU ETS (EU Emissions Trading System) is a cap-and-trade instrument applicable to the power and heavy industry sectors. As a consequence, residential electricity consumption is subject to an upstream **carbon price**.
Third Energy Package – Electricity (D2009/72/EC)	- Electricity generators and suppliers must be **'unbundled'** to produce a competitive electricity market price (*Article 31*). - **Electricity wholesale and retail prices must be the product of market competition** in all Member States (*several Articles*).
Strategic Investment	
Energy Performance of Buildings Directive (EPBD) (2010/31/EC)	- All new buildings must be classified as '**nearly zero-energy buildings'** (NZEBs) by 2020, with any remaining energy requirements substantially satisfied by renewables (*Article 9*).
Renewable Energy Directive (RED) (2009/28/EC)	- **Renewable energy support schemes** must be introduced to meet Member State renewable energy targets for 2020.

Key Strengths

The focus of the existing instrument mix at the EU level is on the standards & engagement pillar of policy. Almost all such instruments focus on encouraging energy efficiency, directly or indirectly, rather than the reduction of CO_2 emissions *per se*. The regulatory push/pull effect (Rennings, 2000) is repeatedly employed, with minimum energy performance standards (MEPS) for new buildings and Energy Efficiency Obligation Schemes (EEOS) for existing buildings providing a technology push towards higher efficiency in regulated energy consumption (through more efficient building envelopes and heating systems, for example), whilst the presence of Energy Performance Certificates (EPCs) and Display Energy Certificates (DECs), by altering consumer preferences through increased awareness, engenders a market pull. The effectiveness of DECs in the UK could be strengthened by mandating their use in private as well as public buildings (Cohen and Bordass 2015). The Ecodesign and Energy Labelling Directives employ the same dynamic for energy-using and energy-related products (and thus, largely, non-regulated energy). Whilst these instruments seek to produce technological change, other instruments, such as the requirement for the installation of smart meters and the use of nudging information (Thaler & Sunstein, 2008) on energy bills (through the provision of benchmarked consumption information), again employ push/pull dynamics to encourage reduced energy consumption through behavioural change. A further collection of instruments seeks to provide confidence in those supplying energy

efficiency and renewable technologies (and encourage high standards), through certification and accreditation mechanisms.

A comprehensive set of standards & engagement instruments to encourage improved energy efficiency is the key strength of the existing instrument mix. A substantial energy efficiency gap, a term first coined by Hirst & Brown (1990), but more recently defined by Allcott & Greenstone (2012) as the 'wedge between the cost-minimising level of energy efficiency and the level actually realised', exists in the EU's residential sector. Wesselink, Harmsen and Eichhammer (2010) estimate the presence of around 80 Mtoe of cost-negative (final) energy efficiency measures available from the use of more efficient appliances and building envelope and system efficiency measures (including heating systems) in the EU residential sector by 2020. This equals around 27% of residential final energy consumption across the EU in 2010 (EC, 2011), the reduction of which would reduce both direct and indirect CO_2 emissions (the extent to which depends on the specific measures introduced, the equipment replaced, and the fuel saved). The presence of information failures, split incentives (particularly the 'landlord-tenant' situation) and satisficing behaviour (discussed above) are all key explanatory factors as to why such unexploited savings opportunities exist (Grubb et al., 2014; Gillingham & Palmer, 2013; Jaffe & Stavins, 1994; Hirst & Brown, 1990). As illustrated in Figure 2, instruments under the standards & engagement pillar of policy are those most appropriate to reduce the impact of such issues. The cost-negative nature of many of the actions these instruments induce or require makes them politically attractive, as evidenced by their strong

presence in the instrument mix, but actually realising the identified energy savings can be problematic in practice, as described below.

Key Weaknesses

Notwithstanding their theoretical appropriateness, the practical effectiveness of many of the instruments under the standards & engagement pillar is in many cases unclear. This is the first key weakness of the existing instrument mix. There are two principal reasons for this; the first of which is low quality or non-implementation by Member States, and poor monitoring and enforcement. For example, MEPS for new buildings required under the Energy Performance of Buildings Directive (EPBD) are often poorly enforced, with compliance often found to be relatively low across Member States (Pan & Garmston, 2012). At present, 17 Member States have, or plan to implement, an EEOS (often in combination with other instruments) to satisfy the requirements of Article 7 of the Energy Efficiency Directive (EED)[3]. However, of these instruments, 8 have major credibility issues, 6 have minor credibility issues, and only 2 have no issues[4]. Additionally, most monitoring, verification, control and compliance regimes have been judged to be inadequate (Rosenow et al., 2015). The second factor is that of initial instrument design. For example, whilst all Member States have a functioning EPC scheme (as also required under the EPBD), their design and structure differ somewhat (often resulting from a slow and partial implementation of the EPBD), producing different levels of clarity and effectiveness (Economidou et al., 2011).

Whilst labels required under the Energy Labelling Directive (ELD) are of a harmonised design across the EU, it is unlikely that this instrument had any significant impact on overall market sizes, structure or product choices amongst consumers for the products covered (Ecofys, 2014). Various factors have been identified as contributing to this. First, the introduction of A+ to A+++ labels appears to have produced confusion and a feeling of diminishing returns amongst consumers, reducing its efficacy compared to the simpler 'A-G' scale used in the first incarnation of the ELD in 1992 (London Economics & Ipsos, 2014; Heinzle and Wüstenhagen, 2012). Secondly, around 90% of appliances covered by implementing measures fall into the 'A' category (Heinzle & Wüstenhagen, 2012), reducing the ability for consumers to differentiate between products. Thirdly, Waide & Watson (2013) found that although energy efficiency is commonly an important factor in purchase decisions for products with energy labels, factors such as capital cost often hold higher importance.

This links to the second key weakness of the existing instrument mix. Even if instruments under the standards & engagement pillar are well designed, implemented and enforced, they may generally only be as effective as economic incentives permit them to be (even required MEPS are subject to cost efficiency clauses[5]). This requires the correct incentives to be delivered, primarily by instruments under the markets & pricing pillar of policy.

As highlighted by Table 1, carbon pricing is only applied to electricity at the EU level via the EU ETS. Other (non-renewable) fuels used in households (such as gas, coal and oil), account for over 60% of energy consumption (and all direct net

CO_2 emissions) from the residential sector[6], mainly for space and water heating. These fuels may be exempt from any form of taxation under provisions of the Energy Taxation Directive (2003/96/EC) (except VAT, although this may be set at a reduced rate of 5%). As a result, markets & pricing instruments are largely absent at the EU level, with (CO_2-intensive) energy consumption able to be effectively subsidised through a reduced-rate VAT (permitted by the VAT Directive), and a failure to internalise the market externality of CO_2 emissions. As such, the incentives for private and socially optimal levels for the installation of energy efficiency measures, reduced demand through behaviour change and the installation of low-carbon heating and electricity generating technologies are misaligned. Additionally, despite legal obligations to the contrary, many Member States maintain regulated electricity prices (EC, 2014), preventing the full communication of the (albeit currently low) carbon price generated by the EU ETS.

Instruments present under the strategic investment pillar of policy in Table 1 do relatively little to alter this picture. This is the third key weakness of the existing instrument mix. The Near-Zero Energy Buildings (NZEB) requirement for new buildings by 2020 is an extension of the existing MEPS requirement, but is included under the strategic investment pillar due to its apparently ambitious nature and the use of currently niche or immature technologies that would likely be required to achieve it. The EPBD allows Member States to set the definition of 'nearly-zero', with many setting such definitions at 45-50 kWh/m^2/year for residential properties (with some Member States yet to set a definition at all (BPIE, 2015)). Additionally, few Member States require any proportion of the

remaining energy consumption to be satisfied by renewables, as required by the EPBD (Ecofys, 2014a). In 2012, the average energy intensity of the existing EU residential stock was 185 kWh/m^2 (Gynther, Lapillionne and Pollier, 2015). As such, it appears that in practice, NZEB requirements are not as ambitious as the name may at first suggest (indeed, Ecofys (2012) suggest that at 2010 energy and technology prices a cost-effective level of energy consumption is 15 kWh/m^2 or lower in four of five climatic zones across the EU, with <25 kWh/m^2 recommended for the coldest climatic zone (which includes Stockholm, Helsinki and Riga)). This is particularly the case if enforcement issues associated with existing MEPS continue.

27 of 28 EU Member States provide financial support for renewable electricity for residential or community-level installations, for a range of technologies (commonly via feed-in tariffs, or increasingly feed-in premiums)[7]. 23 of 28 also provide some form of support mechanism for renewable heating sources and technologies. However, many of these renewable heating support schemes either do not apply to household or community-level installations (or only indirectly, such as support for the production of biogas in agriculture to feed in to the gas grid), or support some technologies but not others (e.g. biomass but not solar thermal), or are relatively weak, for example only offering loans or exemptions from other instruments (e.g. CO_2 taxation), rather than direct financial subsidy.

As such, the focus of the strategic investment pillar of policy at EU level is largely limited in practice to the energy efficiency of new buildings (although with relatively low practical ambition), and the deployment of renewable electricity

generation. The requirement for an EEOS under the EED is considered a standards & engagement instrument rather than strategic investment, due to the relatively low level of energy savings targeted, the flexibility in defining the target at Member State level, and the presence of alternative compliance mechanisms[3].

In summary, the existing EU policy mix places a substantial focus on encouraging short-term uptake of energy efficiency measures that are already cost-efficient at prevailing (albeit effectively subsidised in many Member States) energy prices. However, various design and implementation issues hamper this objective. Additionally, whilst important, considerably more must be done to move beyond this goal if emissions targets are to be met. Most significantly, medium- and long-term requirements and incentives to meaningfully reduce demand for and decarbonise space and water heating in existing properties are either absent or insubstantial. This is by far the largest source of energy demand and CO_2 emissions from the residential building sector, and without attention in the short term to prevent continued high-energy and high-carbon lock-in, achieving the CO_2 abatement trajectory illustrated in Figure 1 may become impossible in practice.

Suggested Priority Reforms

To provide both long- and short-term requirements and incentives for reducing energy consumption and CO_2 emissions from the residential sector, the existing EU policy mix must be strengthened and rebalanced across all three pillars of

policy. The key weaknesses of the EU-level policy mix highlighted above suggest seven priority actions that may begin to achieve this:

- Ensure adequate **enforcement** and **encourage high-quality implementation** of existing and future Directives and provisions (within constraints of the subsidiarity principle). This is a key weakness in the existing mix, under the standards & engagement pillar in particular. Without enforcement, little benefit derives from extending or strengthening existing requirements. High-quality implementation may be encouraged both by specifying a small number of acceptable compliance mechanisms, and by the dissemination of best-practice approaches.
- **Redesign key 'engagement' instruments** to increase their potential effectiveness. For example, the ELD may be revised to re-specify the A-G ratings, and ensure an even distribution of products across categories. In July 2015, the Commission released a proposal to do just this (EC, 2015). Standardisation or dissemination of best practice for other such instruments, such as EPCs, would also likely be beneficial.
- The role of the markets & pricing pillar of policy should be extended by **introducing carbon pricing to heating fuels** and **reducing market distortions**, to broaden the use of carbon pricing beyond electricity and to reduce the implicit subsidisation of fossil fuels and energy consumption. The former may be achieved through various means, such as a revision of the Energy Taxation Directive, or the expansion of the EU ETS (applied upstream). The latter would include ensuring regulated electricity prices are

removed (as per current requirements), and the removal of the ability for Member States to impose reduced rate VAT.

- The role of the strategic investment pillar of policy should also be substantially expanded beyond (relatively low ambition) standards for new buildings (which are likely to account for a minority of the total residential building stock by 2050[8]). Three key actions may be taken to achieve this. The first is to **reform NZEB requirements from 'nearly-zero energy' to 'net-zero energy'**. This would increase ambition against current requirements, and may reduce flexibility surrounding the regulatory limits that may be set by Member States (i.e. interpretations of the meaning of 'nearly-zero', which currently allow for requirements that are significantly less ambitious than the literature suggests would be most cost-effective).
- The second action to expand the role of the strategic investment pillar of policy is to **extend EEOS requirements beyond 2020**, and introduce mechanisms to encourage deep retrofits (for example, through a mandatory proportion of total compliance requirements, or through a compliance 'uplift factor'). An explicit focus **on residential buildings** and a restriction on the ability to use alternative compliance mechanisms, as discussed above, may also prove beneficial.
- The third action to expand the role of the strategic investment pillar of policy is to **require or more directly encourage support mechanisms for residential renewable heating**. Alongside expanded EEOS requirements, this encourages the installation of renewable heating technologies in existing buildings, individually or as district heating, which as discussed above, is a significant shortcoming of the existing policy mix, particularly since heating

accounts for the vast majority of the non-electric energy consumption in residential properties.

The likely impact of such actions depend substantially on the specific design such instruments take, and the specific implementation in individual Member States, and as such should be assessed in future work. Regardless, it is likely that such actions alone would not be sufficient to achieve the rates of decarbonisation identified in Section 1. Beyond the policy instrument landscape as defined here, appropriate long-term planning and governance infrastructures will also be required. However, such aspects are beyond the scope of this paper.

The Policy Landscape - United Kingdom

This section describes the experience of the UK since 1997 [9] in its implementation of measures to improve the energy efficiency and reduce (direct and indirect) CO_2 emissions from the residential sector. Many of the instruments introduced were in response to EU legislation, described in the previous section, and therefore illustrate how one Member State sought to transpose such legislation into national policy. Other instruments precede such requirements (for example, the UK energy efficiency obligations), and may even have led to, the EU legislative provisions described above. The UK is taken as an example because of its strong national legislation on climate change with ambitious emission reduction targets. Other Member States will, of course, have responded differently to the EU legislation described above.

<Table 2 – Policy Landscapes across the 'Three Pillars' – United Kingdom>

Type and Name of Intervention	**Description of Intervention**	**Effectiveness Evaluation** **Energy/Carbon saved; Cost savings; Renewable power**
Standards & Engagement		
Energy Efficiency Standards of Performance (EESoP)	EESoP ran in three phases from 1994-2002, and led to the principle of energy suppliers being obligated to help their customers save energy through energy efficiency measures being incorporated in UK law through the Utilities Act (2000). The main measures delivered were insulation, lighting, heating and appliances.	The National Audit Office in 1998 calculated that the overall net financial benefit of EESoP1 (1994-98) was £250 million (Ofgem and Energy Saving Trust, 2003).
Energy Efficiency Commitment (EEC)	EEC, a supplier obligation that built on the experience of EESoP, was implemented in two phases. EEC1 ran from 2002-05 and EEC2 from 2005-08, with 'lifetime' energy savings targets of 62TWh and 130TWh, and projected costs of £500m and £1.2 billion, respectively (Rosenow, 2012).	Estimated energy savings from EEC1 were substantially in excess of its targets, and were delivered for electricity and gas at a cost of 1.3p/kWh and 0.5p/kWh respectively, far less than the retail price (Lees, 2006, p.6). The targets of EEC2 were also substantially exceeded, with EEC1 and EEC2 together estimated to be saving by 2010 6.1 and 7.4 TWh of electricity and natural gas, with the EEC2 cost being 2.1p/kWh and 0.6p/kWh, respectively – less than a quarter of the average price to consumers of those fuels in EEC2. The life time carbon dioxide savings from meeting the EEC2 target were estimated as 59 $mtCO_2$, yielding a Net Present Value of £53/tCO_2 saved (Lees, 2008, p.6).
Carbon Emissions Reduction Target (CERT) and Community Energy Saving Programme (CESP)	The target for CERT, introduced in 2008, was lifetime carbon savings of 293 $mtCO_2$, estimated to amount to 104TWh of energy. The estimated cost over 2008-12 was £5.5 billion (Ofgem, 2015a) This implies a cost of carbon saving of £18.8/tCO_2. The lifetime CO_2 savings target for CESP was set at 19.25 $mtCO_2$, at an estimated cost of £332 million (Martin, de	CERT carbon savings were estimated as 296.9 $mtCO_2$, 101% of the target. For CESP the estimated delivery against the target was 16.31 $mtCO_2$, or 84.7% of the target. CERT savings were delivered at an estimated cost of £3.65 billion, well below the *ex ante* estimation. The cost of carbon savings was estimated at £13.79/tCO_2, also well below the *ex ante* estimation. In contrast,

	Preux, and Wagner, 2011).	the cost of CESP was estimated at £702 million, more than twice the *ex ante* estimation, while carbon savings of 20.2 $mtCO_2$ just exceeded the target, implying a cost of carbon saving of £34.8/tCO_2 (Ipsos Mori *et al*, 2014).
Energy Companies Obligation (ECO, ECO2)	Following on from CERT, ECO, running from 2013-15, required obligated suppliers to achieve carbon and cost savings in respect of three distinct obligations: the carbon emissions reduction obligation (CERO), which promotes the installation of solid wall and hard-to-treat cavity wall insulation; the carbon saving community obligation (CSCO), which promotes the installation of insulating measures and connections to district heating systems in areas of low income and rural areas; and the home heating cost reduction obligation (HHCRO, which promotes the installation of measures, including the repair and replacement of boilers, to homes in receipt of certain benefits, to reduce the overall cost of space heating). ECO2, with the same obligations, was introduced to run from 2015-17. Targets under the different obligations for ECO and ECO2 were, respectively: CERO 20.9 (later reduced to 14.0), and 12.4 $mtCO_2$; CSCO 6.8 and 6.0 $mtCO_2$; HHCRO £4.2 and £3.7 billion. (Ofgem, 2012; Ofgem, 2015).	The monthly ECO Compliance Update for April 2015 produced by Ofgem showed that the targets to the end of March 2015 had been over-achieved, with the exception of the HHCRO rural sub-obligation, which had achieved a 99% compliance, but with many measures in the pipeline (Ogem, 2015)
Green Deal	The Green Deal policy was enabled through the Energy Act 2011. Its main novel provisions were the ability of a householder to take out a loan for energy efficiency measures which was repaid through the energy bill of that property, even if the householder moved, when the repayments would	The Green Deal achieved far less take up than had been hoped – only 15,000 by 2015. In July 2015 the new Conservative UK Government announced that it would not continue funding the Green Deal through the Green Deal Finance Company that had been set up for this purpose. While in principle Green Deals

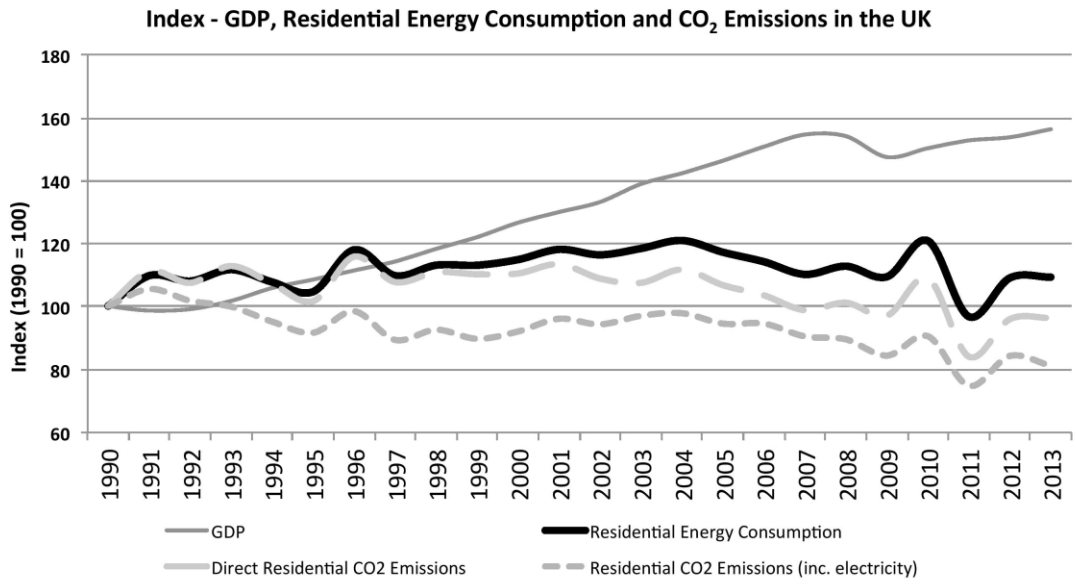
	continue for the new householder in the property. The measures needed to be those recommended and installed by individuals and companies with appropriate certification, and only those measures would be recommended which were calculated to pay back their cost within their lifetime – the 'Golden Rule' (DECC, 2010).	could continue to be financed privately, the announcement was widely interpreted as amounting to the end of the policy.
Markets & Pricing		
Climate Change Levy (CCL)	The CCL was introduced in 2001 as a combined carbon-energy tax on business. Energy intensive firms were largely exempted provided they signed up to Climate Change Agreements (CCAs). The exemption for renewables was ended in 2015, making the CCL almost wholly an energy tax.	The UK National Audit Office evaluation in 2007 agreed with "the most recent estimate of annual savings of 3.5 MtC in 2010" from the CCL, and 1.9 MtC from the CCAs (NAO, 2007). A different 2011 evaluation found that the CCL "caused plants paying the full rate to reduce CO_2 emissions by between 9.6% and 22.6% compared to plants [covered by the CCAs] that paid the reduced rate." (Martin *et al*, 2011, p.28). No evidence was found that the CCL had adversely affected the competitiveness of UK manufacturing.
Carbon Price Floor (CPF)/Carbon Support Price (CSP)	The CPF was introduced in 2011 and was intended to provide a minimum price for carbon in the power sector, rising from £16/tCO_2 in 2013. It consists of the EU ETS allowance price, plus the CSP, which is calculated two years in advance and levied on the fossil fuel inputs to power generation, to deliver the projected minimum price, originally intended to be £30/tCO_2 in 2020, and £70/tCO_2 in 2030. Because of the weakness of the EU ETS price, the CPS was frozen at £18/tCO_2 in 2014.	No evaluation yet available, but the government estimated in its impact assessment that the CSP would cumulatively reduce emissions by 261mtCO2 over 2013-30 (HM Treasury & HM Revenue and Customs, 2010, pg.13).
Strategic Investment		
Non-Fossil Fuel Obligation (NFFO)	NFFO was introduced in England and Wales through the 1989 Electricity Act (with similar legislation being introduced in Scotland and	The total NFFO renewable generation target was 1500 MW, but by 2003 only 1098MW had been built (Tovey, n.d), with many contracted projects not

	Northern Ireland). The Act allowed the government to require public electricity suppliers (PES) to purchase a certain amount of electricity produced from non-fossil fuels, and levied a charge on consumers, the Fossil Fuel Levy (FFL), to compensate the PES for the NFFO. Most of the revenues from the FFL went to the subsidise the nuclear industry, but NFFO itself supported renewables through five orders, the first in 1990, the fifth in 1998, paving the way for the introduction of the more ambitious Renewables Obligation in 2002.	proceeding to construction. The NFFO installations generated around 3% of 2003 total UK electricity (around 380TWh).
Renewables Obligation (RO)	The Renewables Obligation came into force in 2002 in England, Wales and Scotland, and 2005 in Northern Ireland. It places an obligation on the main electricity suppliers to source an increasing proportion of their generation from renewable sources. The obligation is met by presenting Renewables Obligation Certificates (ROCs) at the end of year, or paying a 'buy out price' per MWh of shortfall in renewables supply. The RO is due to terminate in 2017, to be replaced for the CfD.	Renewable electricity generation increased from less than 3% of total generation in 2000 to around 19% of generation in 2014 (DECC, 2015a). Pursuant to its manifesto commitment, the new Conservative UK Government announced in July 2015 that it was closing the RO for new onshore wind in 2016. It also announced that, in order to reduce subsidy costs, it was limiting the eligibility of biomass plants that were converting from fossil fuels.
Contracts for Difference (CfD, a premium FiT)	Contracts for Difference (CfD) were introduced as part of the Electricity Market Reform in the UK Energy Act 2013. They comprise a payment to generators of the difference between the average wholesale price or electricity and a (higher) technology-specific 'strike price', to apply to low-carbon technologies (renewables, nuclear and carbon capture and storage). CfDs will replace the RO from April 2017.	The first CfD auctions, in February 2015, awarded contracts to 27 projects (onshore and offshore wind, advanced conversion, solar PV and energy from waste with CHP), with a total capacity of 2.1GW and an estimated subsidy of £315 million per annum by 2020/21. The strike prices were substantially below those anticipated in advance (e.g. £115-120/MWh for offshore wind, as against £140/MWh)
Feed-in-Tariffs (FiT)	While the RO and CfDs are intended to support larger-scale	By the end of 2014 FiTs had led to the accreditation of 3.25GW

	renewables, FiTs, first introduced in the UK in 2010, apply to smaller projects for solar PV, wind, hydro, domestic CHP and anaerobic digestion.	renewables capacity, 83% of which was solar PV (DECC, 2015a). The tariff rate has been repeatedly reduced (e.g. for solar PV <4kW from over 40p/kWh in 2010 to around 13p/kWh in October 2015) (Ofgem, 2015b).
Renewable Heat Incentive (RHI)	The RHI applies to both non-domestic and domestic installations of eligible renewable heat technologies (including solid biomass, heat pumps, geothermal, solar thermal. biogas combustion and biomethane injection), with the former introduced in 2011 and the latter in 2014.	By mid-2015 1GW of renewable heat had been installed under the non-domestic scheme, nearly 99% of which was solid biomass (Ofgem, 2014b). In the first six months of its operation (by Ocober 2014), there were 10,000 domestic RHI accreditations (Ofgem, 2014a).
Zero Carbon Homes (ZCH)	The ZCH policy, introduced in 2006, required all new homes from 2016 to avoid or mitigate all regulated emissions using a combination of on-site energy efficiency measures (such as insulation and low energy heating systems), on-site zero carbon technologies (such as solar panels) and off-site measures to deal with any remaining emissions.	In July 2015 the new Conservative UK Government announced that it did not intend to proceed with the 'zero carbon' carbon offsetting scheme, or the proposed 2016 increase in on-site energy efficiency standards, but would keep energy efficiency standards under review. It is not clear what the implications of this are for the NZEB requirements for the European EPBD.

Table 2 lists the various instruments introduced in the UK to promote the decarbonisation and more efficient use of residential energy, with two pre-1997 instruments (Energy Efficiency Standards of Performance [EESOP] and the Non-Fossil Fuel Obligation [NFFO]) listed as important precursors of subsequent instruments.

Key Strengths



<***Figure 3*** *- Indices of GDP, household energy use and CO_2 emissions, 1990-2013 (1990=100)*>[10]

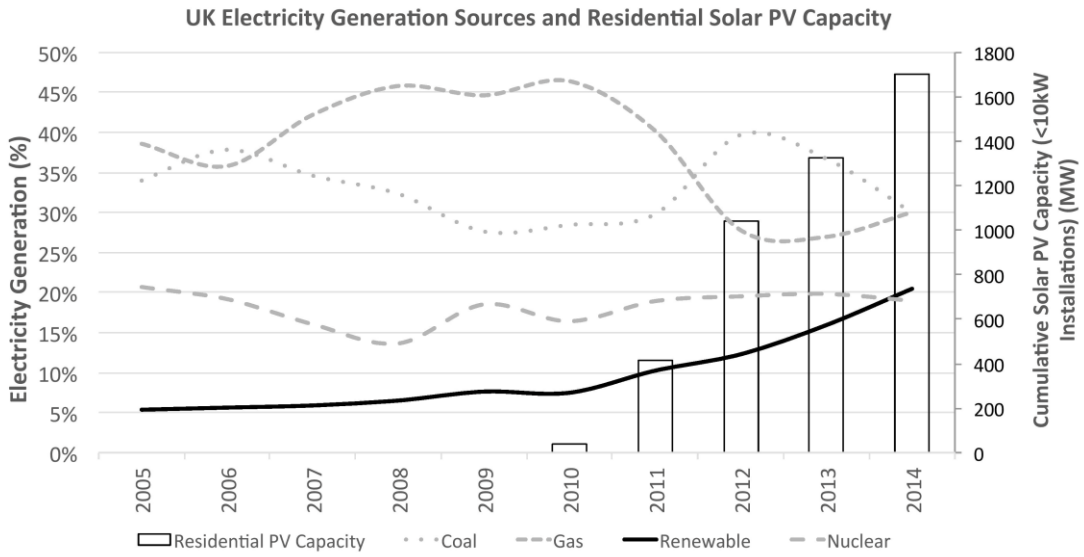
Figure 3 shows that UK residential energy use has fallen consistently since 2005, despite periods of strong economic growth, showing a clear departure from the energy-economy coupling of the 1990s. By 2013, although total residential energy use was 9% above that in 1990, energy use per household was 8% lower, and 35% lower per unit of disposable income[11]. Figure 3 also presents the evolution of CO_2 emissions arising from this energy use. Two-thirds of residential energy consumption in the UK is fossil fuel (primarily natural gas) combustion for space and water heating[12]. Therefore, both direct and total CO_2 emissions track energy use trends closely. The divergence in total emissions is due to the decarbonisation of UK electricity from around 740 gCO_2/kWh in 1990 to 459 gCO_2/kWh in 2013[13]. Despite the decrease over time, total direct CO_2 emissions from the UK's residential sector was second only to Germany in 2012, and the fourth highest in proportion to total domestic CO_2 emissions[14]. The UK

must therefore continue to drive substantial reductions over time, driven by an appropriate policy framework.

There is as yet no convincing evidence to attribute specific CO_2 emission reductions to specific policy instruments and other (non-policy) influences, but it is likely that both aspects have contributed to the trends illustrated in Figure 3. However, in the 1990s the major cause of the reduction in total residential CO_2 emissions was undoubtedly the substitution of gas for coal in power generation (driven by market forces in the newly-privatised sector, rather than policy drivers), producing the reduction in CO_2 intensity described above. A reverse in this trend and the 2009-2011 recession contributed substantially to the volatile trend experienced in 2008-12. However, it is clear that a comprehensive strategic investment pillar of policy had an effect. This is the first key strength of the UK's policy mix.

The Renewables Obligation (RO), and, most recently, a premium Feed-in-Tariff (FiT) called Contracts for Difference (CfD), are the UK's main strategic investment instruments for incentivising the deployment of large-scale low-carbon power generation, with a fixed-rate FiT encouraging mainly smaller-scale low-carbon power generation. As noted in Table 2, the RO required an increasing proportion of power generation to come from renewables, with penalties paid for a shortfall, while CfD operates through a guaranteed 'strike price' to come from the wholesale power market supplemented by a levy on consumers. The FiT provides both a generation tariff (differentiated by technology and installation size), and an export tariff (equalised across all installations). Figure 4

shows the evolution of the UK electricity mix from 2005-14, and the uptake by households of the FiTs for solar PV since their introduction in 2010. It can be seen that both the RO (for large-scale renewables) and FiTs have been highly successful in incentivising the deployment of renewable electricity capacity (such data is as yet unavailable for the CfDs), which in turn will have contributed to the reduction in CO_2 intensity of power generation (and subsequent residential CO_2 emissions from associated electricity consumption) shown in Figure 3.



<***Figure 4*** *- UK Electricity Generation Sources and Residential Solar PV Capacity*>[15]

These instruments are in place to meet the requirements of the EU Renewable Energy Directive (and the preceding 2001 Renewable Electricity Directive), as described in the previous section[16] (although, the UK's NFFO, which also sought to deploy renewable electricity capacity, preceded these obligations by over a decade). By encouraging the deployment of renewable heating technologies in a manner similar to the FiT for electricity generation (generation tariff***),*** the

(domestic) Renewable Heat Incentive (RHI) was the first of its kind in the world when introduced in 2011, and also seeks to contribute to the UK's obligations under the Renewable Energy Directive[16]. The RHI remains a unique instance in the EU of incentivising the deployment of renewable heating in such a direct manner.

The remaining instrument in the strategic investment pillar of policy is the Zero Carbon Homes (ZCH) requirement, through which new residential properties needed from 2016 to achieve zero net CO_2 emissions through a combination of an increase in regulated energy efficiency requirements, on-site renewable electricity generation (for example, through rooftop solar PV) and off-site 'allowable solutions' to offset remaining CO_2 emissions. The instrument was intended to align with the EU's NZEB requirements (described in the previous section). However it was cancelled in 2015 (one year before it was due to come into force). It is now unclear how the UK intends to comply with NZEB requirements (although MEPS remain as part of the UK's building regulations (Part L), satisfying current EPBD requirements). Also, as with the EU-level policy mix, instruments to tackle energy consumption in existing buildings in the strategic investment pillar of policy are lacking.

The second key strength of the UK's policy mix, as at the EU level (and deriving directly from it), is a comprehensive standards & engagement pillar of policy. This includes both instruments that seek to achieve the UK's compliance with EU obligations, and those that apply equally across the EU. The Ecodesign and Energy Labelling Directives are the key examples of the latter. Regarding the

former, the key instruments are the subsequent supplier obligations – the successive EESoP, EEC, CERT/CESP and ECO (see Table 2 for spelled-out versions of these acronyms). As mentioned above, the use of such instruments in the UK significantly preceded EU requirements (the EED was introduced in 2012, whilst the EESoP was adopted in 1994). The final key instrument in the standards & engagement pillar of policy is the Green Deal, discussed below..

Key Weaknesses

The UK's policy mix contains three key weaknesses., The first, as at the EU level, is the effectiveness of the instruments under the standards & engagement pillar. For new buildings, Pan & Garmston (2012) found that of a sample taken of residential properties built between 2006 and 2009 in the UK, only a third were in compliance with MEPS for new-build properties. Indeed, awareness of regulations for existing buildings is very low, even among the construction industry (CLG, 2006).

For supplier obligations designed to tackle energy consumption and CO_2 emissions from existing buildings, a 'delivery gap' between reported and actual impact may be identified. Under these instruments, energy suppliers were assigned energy or CO_2 saving targets to be achieved over defined periods - the majority of which were officially achieved or even over-achieved (as illustrated in Table 2). However, doubts have been expressed as to whether the imputed energy and CO_2 savings from the installed measures have been achieved in practice. The evaluation of the performance of such instruments is usually based

on engineering and modelled estimates of how the installed technology will perform, rather than actual measured savings – an approach that routinely overestimates actual outcomes (Rosenow & Galvin, 2013). Although the UK compares relatively favourably with other EU Member States (such as Germany) in considering in some calculated evaluations (for example, in the evaluations of Efficiency Commitment by Lees (2006 and 2008)) phenomena that produce such discrepancies between calculated and measured results, such as rebound effects, 'prebound effects' (coined by Sunikka-Blank and Galvin (2012), and referring to a situation in which energy consumption prior to the introduction of a policy instrument is overestimated), technical shortcomings in installed measures, and deadweight losses (from householders that would have taken the action encouraged by the policy regardless of the instrument's existence) (Rosenow & Galvin, 2013), the evidence suggests that some discrepancy between actual and calculated savings, as used to demonstrate compliance, remains.

The current supplier obligation incarnation, the ECO, has thus far resulted in a sharp reduction in the number of energy efficiency measures installed compared to previous instruments (particularly CERT/CESP). This stems from a re-orientation towards more expensive measures such as solid wall and hard-to-treat cavity wall insulation, and an increase in the paperwork required for the approval of these measures. This has made it more difficult to include the new approach in existing business models. Additionally, the financial contribution required by consumers has also increased. It is estimated that in 2014, the combined ECO/Green Deal package delivered measures that will produce 74% less energy and 86% less CO_2 lifetime savings than those installed annually on

average between 2008 and 2012 under the previous CERT/CESP instrument package (Rosenow & Eyre, 2015).

Although introduced as part of a policy package with the ECO, the Green Deal was not introduced in (direct) response to EU requirements, but in addition to them. As described in Table 2, the instrument was effectively discontinued in 2015. The Green Deal contained a number of innovative elements (for the UK), to encourage householders themselves to invest in regulated energy efficiency measures. Principal among these was the availability of a loan for pre-approved regulated energy efficiency measures attached to the property rather than the householder (and thus liable for repayment by successive occupiers), with monthly repayments made via electricity bills at a level designed to be equal to or lower than the value of energy cost savings as they accrued (the 'Golden Rule'). This was intended to overcome barriers associated with capital costs, the landlord-tenant dilemma, and uncertain returns on investment (if, for example, a householder were to leave before their return on investment had been achieved).

However, the instrument significantly underperformed against expectations, with only 626 householders taking part by the end of 2013, against an expected figure of 10,000. Rates of uptake did increase, but remained well below expectations. Several factors likely contributed to this, including initial problems with the IT administration system and the late availability of the loan facility (introduced five months after the launch of the instrument itself), but particularly the interest rate of the loan, which survey evidence suggested that,

at around 7.5%, was considered too high by householders (Rosenow & Eyre, 2015). Other issues included uncertainty surrounding the long-term financial benefits of undertaking regulated energy efficiency measures (Petitfor, Wilson and Chryssochoidis, 2015), and a possible perception that with the loan attached to the property, with subsequent occupiers liable for repayment, the sale value of the property would be reduced (Ashworth & Perera, 2015). When in June 2014 capital grants (the Green Deal Home Improvement Fund) were introduced with the intention to stimulate uptake of Green Deal finance, they were very quickly oversubscribed, with the second tranche of funding allocated within a single day, but it seems that many householders simply accepted the grant with little or no intention of supplementing this with a Green Deal finance package, as per the intended function (Rosenow & Eyre, 2015).

The second key weakness of the UK's policy mix, again aligned to the EU-level mix, is the paucity in coverage of markets & pricing instruments. The CCL and CFP/CSP (see Table 2 for spelled-out acronyms) are the UK's main energy and carbon pricing instruments (alongside the EU ETS, applied at the EU level). Whilst the former only applies directly to the energy consumption of (all except the smallest) firms, the associated costs feed through to goods purchased by the residential sector. The latter, as described in Table 2, attempts to provide a UK-specific carbon floor price, on top of the EU ETS, which feeds through into the price of electricity. However, CO_2 emissions from remaining sources of energy in the residential sector (75% of energy consumption in 2014) remain unpriced[12]. The CFP rate was initially intended to increase to £30/tCO_2 by 2020, and to £70/tCO_2 by 2030, but, due to the low EU ETS permit price and concerns about

the CSP's impacts on the competitiveness of UK industry, the CSP is currently frozen at £18/tCO_2 until 2020.

In addition, as permitted by the EU's VAT and Energy Directives, the UK levies a reduced-rate (5%) VAT on residential energy consumption (the standard VAT rate is 20%). The implicit annual subsidy to households that this represents is approximately £5bn (Advani et al., 2013), although less than 30% of the implicit subsidy is taken households in the bottom three income deciles (Preston et al., 2013). Residential energy prices in the UK currently exhibit the lowest tax and levies component in the EU (EUROSTAT, 2016). However, this is offset to some extent by on-bill levies from other climate and energy policy mechanisms (e.g. FiTs and RO/CfDs).

The third key weakness, common to all three pillars of policy, is a lack of stability and long-term credibility in the policy instrument landscape in the UK. Since its election in May 2015, the new UK Government has removed or significantly amended several low-carbon energy instruments with little or no notice or indication of replacements where required the UK's statutory carbon and energy targets. Regarding the promotion of low-carbon electricity, this includes removal of support for onshore wind and termination of its eligibility for the RO one year early, and an abrupt 65% reduction in the FiT (generation tariff) for small-scale (household) solar PV (<4kW) applicable from 1st January 2016. The Green Deal and ZCH were also both discontinued at short notice[17], with no replacement instruments yet proposed, reducing focus on regulated energy efficiency in both

new and existing residential properties. A number of other changes which fall outside the scope of this paper were also instituted.

The key reason behind such changes was the perceived high cost of these instruments[18]. Regardless of the evidence for and against the assertion of high costs, the institution of such abrupt interventions, and a lack of a forthcoming strategy with which to replace the functions of such instruments where required, has produced numerous accusations of substantially undermining investor confidence in the low-carbon sector in the future (e.g. Cuff, 2015; Gross & Watson, 2015; Grubb et al, 2015).

Suggested Priority Reforms

As indicated above, many of the key weaknesses in the UK's policy landscape mirror those at the EU level. As such, the suggestions for priority reform that may be derived to increase the effectiveness of these instruments are of a similar nature. Six such reforms are here proposed:

- Improve **enforcement of MEPS for new buildings**. Low enforcement (and awareness) of these requirements is a key issue in the standards & engagement pillar of policy. Such action would further lay the foundation for increased ambition, as discussed below.
- Introduce an instrument to **replace the function of the Green Deal.** The original instrument was subject to various design flaws and other barriers to uptake, as described above. However lessons learned may be applied in order

to introduce an improved instrument to fulfil the function as originally intended (see e.g.. Rosenow & Eyre, 2015). Such a reform may also improve the functioning of the ECO (e.g. if householders were to receive a loan to finance their contribution to a measure particularly funded by ECO – currently a key barrier, as described above). This, along with the reform above, may substantially strengthen the standards & engagement pillar of policy at the UK level.

- As at the EU level, the markets & pricing pillar of policy should be extended and strengthened. This may be achieved by three key actions. The first is to extended **carbon pricing to heating fuels**, to broaden carbon pricing from 30% of residential energy consumption (electricity) in the UK, to 80% of energy consumption (if a carbon price were applied just to natural gas for heating purposes)[11] .
- The second action to strengthen the markets & pricing pillar of policy is gradually to **increase the reduced-rate of VAT on domestic energy consumption** (e.g. by 1% per year), to reduce and eventually remove the implicit energy consumption subsidy this produces. Although undoubtedly politically challenging, governments, including that of the UK, repeatedly affirm their determination to remove environmentally perverse subsidies[19], and this is the largest such subsidy in the UK. Analysis suggests that the reform could be implemented with progressive (rather than regressive) consequences, through, for example, appropriate recycling of increased VAT revenue (Preston et al., 2013).
- The third action to strengthen the markets & pricing pillar of policy action is to restore the original trajectory of the CFP (to reach £30/tCO_2 in 2020 and

£70/tCO_2 in 2030). This would strengthen the carbon price on the electricity sector, but this action seems unlikely in the absence of any strengthening of the EU ETS permit price component of the CFP.

- Introduce an instrument to **replace the function of the ZCH instrument**, to restore coverage of energy efficiency in (and direct CO_2 emissions from) new residential properties under the strategic investment pillar of policy. This would also seek to satisfy NZEB requirements.

As many of these suggested reforms align with those at the EU level, it may be noted that reform of the policy mix at the EU level may feed through to the UK level (e.g. removal of the ability to levy reduced-rate VAT on residential energy consumption, or EU-level expansion of carbon pricing). However, there currently seems to be little political appetite for such EU-wide reforms (as was seen, for example, with the rejection of a revised Energy Taxation Directive proposed in 2011). Other actions may only be instituted at the national level, such as proper enforcement of building regulations (although such action may be encouraged at the EU level, through infringement proceedings), and the avoidance of abrupt interventions into the policy landscape, with unclear intentions into the medium- and long-term.

Conclusion

CO_2 emissions from the residential sector make a significant contribution to overall GHG emissions in the EU and constituent Member States, and must be substantially reduced if the projected decarbonisation of the EU is to be

achieved. This paper has explored the policies that are currently in place to achieve this reduction, using the policy framework suggested by Grubb et al. (2014), which groups instruments into three 'pillars of policy'; standards & engagement; markets & pricing; and strategic investment.

This paper first maps the policy landscape for energy use by residential sector in terms of this framework at both the EU level and in an illustrative Member State, the UK. It then identifies the key strengths and weaknesses of each revealed policy mix according to the scope of energy consumption and associated CO_2 emissions tackled, and the effectiveness of the collection of instruments in each pillar in achieving their objectives.

The key strengths and weaknesses of the policy mix at both the EU and UK levels are heavily aligned, as may be broadly expected, given the UK obligations under the EU landscape. Both policy landscapes exhibit a rich policy mix under the standards & engagement pillar of policy, with various instruments designed to tackle (both regulated and non-regulated) energy consumption and CO_2 emissions from both new and existing buildings (with some introduced directly at the EU level without Member State-specific implementation required, such as the Ecodesign and Energy Labelling Directives). This is the first key strength of each policy mix (and the only key strength identified at the EU level). Until recently the UK went beyond EU requirements, with the 'Green Deal' seeking to encourage private investment for improving regulated energy efficiency in existing buildings in addition to mandated supplier obligations. However, this instrument was effectively discontinued in 2015.

The second key strength of the UK's policy mix was (until recently) a relatively comprehensive strategic investment instrument mix, with effective renewable electricity and renewable heating support mechanisms, and until mid-2015, an instrument to promote net-zero carbon new residential buildings from 2016 (Zero Carbon Homes). By contrast, the strategic investment pillar is a key weakness at the EU level, with 'nearly-zero' energy requirements for new buildings (with low ambition in implementation by most Member States), no requirement for the promotion of renewable heating, and no instrument to tackle energy consumption in existing buildings from this perspective (an issue shared with the UK).

The two remaining key weaknesses across both policy landscapes are low effectiveness of the instruments under the standards & engagement pillar (despite broad coverage), and low coverage and effectiveness of instruments under the markets & pricing pillar. The first stems from low quality or under-implementation of instruments at Member State level, poor enforcement, and ineffective instrument design. The second stems primarily from a lack of carbon pricing on non-electricity energy products for residential consumption, and the ability to effectively subsidise residential energy consumption through reduced-rate VAT (as implemented in the UK). In addition, the UK has recently experienced significant abrupt alterations to the policy landscape, with no clear long-term strategy to replace the intended functions of instruments that have been removed, with possible impacts on investor confidence.

A range of priority reforms may be instituted to address the weaknesses identified at both the EU and UK levels. Such reforms common to both levels of governance include improved enforcement of regulatory requirements (particularly MEPS for new buildings), the expansion of carbon pricing to heating fuels coupled with the removal of reduced-rate VAT for residential energy consumption (and the implicit subsidy it entails), and reform of the strategic investment pillar to require net-zero energy new buildings and a post-2020 commitment for supplier obligations to tackle energy consumption in existing buildings. Such reforms may be introduced at the EU level for subsequent application to all Member States (including the UK), or may be introduced at the UK level only. Additional reforms, such as the redesign of key 'engagement' instruments, along with the requirement (or direct encouragement) for Member States to introduce renewable heat support mechanisms in the EU policy mix, and the introduction of a mechanism to replace the Green Deal at the UK level, may also be identified as priority actions.

It is clear that all these reforms would require considerable political will that is currently lacking, and is unlikely to be forthcoming in the short term, especially as both the EU and UK seem to be on track to meet or exceed their economy-wide emission reduction targets for 2020 (EEA, 2015b). However, the EEA (2015b) project that economy-wide EU GHG emissions are likely to reach just 27% below 1990 levels by 2030 under existing measures (and 30% under 'planned measures'), falling far short of the 40% target. This places the 2050 target of 80% in significant doubt. As such, it is imperative that new policies for reducing residential energy use and associated CO_2 emissions are introduced, or

the existing policy mix implemented more effectively, or both, in order to achieve the emissions trajectory for the sector illustrated in Figure 1, and in turn contribute to long-term economy-wide objectives that are at present on track to be missed. By identifying the scale of the challenge, and examining the strengths and weaknesses of the present policy landscapes at both the EU level and in a key Member State, this paper hopes to make some contribution to that outcome.

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[1] Much of the research reported here was carried out in the context of the EU FP7 project CECILIA2050 (see http://cecilia2050.eu/) over 2013-14. However, for this paper the research has been up to date.

[2] Data for 2011 and 2012 illustrate annual CO_2 reductions of 16% and -4% (an increase), respectively on the previous year (an average annual reduction of 6%) (EEA, 2015a). Data for 2013 onwards is not yet available, and thus the presence of a long-term trend cannot be discerned (particularly due to the substantial variability seen between these two years).

[3] Although this target is economy-wide, EU ETS and transport sectors may be excluded. Other instruments such as CO_2 taxation, training and information campaigns or the creation of an 'Energy Efficiency National Fund' may also be used to secure compliance if equivalent energy savings are produced. The remaining 11 Member States intend to use such mechanisms alone to secure compliance.

[4] 'A 'minor' credibility issue is defined as that in which 'confidence that the policy package as notified by the Member State will realise 90% or more of the required target', whilst a 'major' credibility issue is defined as that in which the 'risk that the policy package as notified by the Member State will realise less than 90% of the required target either due to insufficient policy savings and/ or significant methodological issues' (Rosenow *et al*, 2015). The final Member State, Portugal, has an existing EEOS instrument in place but has not notified the Commission of their intention to use this for Article 7 compliance, and thus instrument credibility was not assessed by this study.

[5] Member States are not required to set minimum standards which are not cost-effective over the economic lifecycle of the building elements concerned, as determined using the comparative methodology framework described in Article 5 and Annex III of the Directive.
[6] Data for 2013 and the EU28, obtained from Eurostat.
[7] Data Source: http://www.res-legal.eu/compare-support-schemes/
[8] DG Energy (20112) estimate that 75% of the EU's building stock standing in 2005 will remain present in 2050.
[9] This date has been chosen because it was the year of the signature of the Kyoto Protocol, which set statutory GHG emission reduction targets on industrial countries for the first time, and it was the year of the election of a Labour Government, which introduced many of the instruments to be discussed.
[10] Data sources: UK Office of National Statistics and Energy Consumption in the UK (domestic data tables).
[11] Data Source: Energy Consumption in the UK (ECUK) Statistics, Table 3.35
[12] Data for 2013, from DUKES, Chapter 3 (domestic data tables).
[13] DEFRA GHG conversion factors
[14] Direct CO_2 emissions from the UK residential sector were 74 $mtCO_2$ in 2012, and 94 $mtCO_2$ in Germany. In proportional terms, these emissions account for 15.4% of the UK's total CO_2 emissions in that year, exceeded only by Belgium (16.4%), Ireland and Hungary (both 15.9%) (EEA, 2015a).
[15] Data Sources: DUKES and DECC Statistics
[16] The UK must achieve 15% of its gross final energy consumption from renewables by 2020 (from electricity, heating, cooling and transport), Under the 2001 Renewable Energy Directive., the UK was required to produce 10% of gross electricity generation from renewable sources.
[17] The ZCH instrument had been in place since 2006, for compliance to be achieved by 2016. The instrument was cancelled in mid-2015.
[18] The cost of renewable support mechanisms is projected by government to rise to £9.1 billion per year by 2020 – £1.5 billion above the limit set by the Levy Control Framework (DECC, 2015b), whilst the ZCH was removed to 'reduce net regulation on housebuilders', (HM Treasury, 2015), in order to encourage increased building rates.
[19] See, for example, the Leaders' Declaration from the 2015 G7 Summit at Schloss Elmau, which stated explicitly: "We remain committed to the elimination of inefficient fossil fuel subsidies …" (https://www.bundesregierung.de/Content/EN/Artikel/2015/06_en/g7-gipfel-dokumente_en.html)