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The political economy of electricity system resource adequacy and renewable energy integration: A comparative study of Britain, Italy and California

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ABSTRACT

The need to integrate growing shares of variable renewable resources, like solar and wind, into the power system has initiated a new wave of resource adequacy policy reforms. Securing adequate resources on the system, particularly flexible and peak capacity, is indeed crucial for ensuring long-term grid reliability amid increased supply variability. While extensively explored from a techno-economic perspective, the political economy drivers and implications of these changes are frequently overlooked. Yet, power system evolution is not merely shaped by logics of techno-economic optimisation, it is also inherently political, rooted in specific liberalisation histories, political and institutional settings.

This paper contributes to the literature by conducting a comparative political economy analysis of recent resource adequacy reforms in Britain, Italy, and California. It explores how differences in the technical and political economy contexts of these jurisdictions affected their strategies for securing resource adequacy capacity and investment between 2013 and 2021. Conclusions draw on the analysis of over 134 policy documents and 53 in-depth interviews with power system stakeholders.

All jurisdictions introduced significant changes in resource adequacy policy, including explicit out-of-market mechanisms to remunerate resource adequacy capacity. The energy transition is thus reconfiguring state-market relations in the power sector, even in traditionally liberal countries. However, variation exists in the scope of reform, mechanism designs, policy trade-offs, and technological outcomes. This stems from context-specific political priorities, state-market relations, national and multi-level governance arrangements, market structures and stakeholder interests. This has important implications for power sector governance, as discussed in this paper.

1. Background and introduction

Decarbonising the electricity supply is vital for meeting climate change targets. Power generation directly contributes to a significant share of global emissions (approximately 40 %) and plays a key role in enabling the wider decarbonisation of the economy. Thanks to targeted policy support, some jurisdictions achieved significant levels of variable renewable energy (VRE) adoption, particularly solar and wind generation [1–3]. While this is a great success story, their experiences reveal that integrating these resources into the power system comes with a set of challenges that call into question legacy electricity sector arrangements, originally designed around fossil fuel resources [ibid].

A significant challenge faced by policymakers in the context of this

changing landscape is ensuring appropriate levels of resource adequacy, or the ability of the system to adequately serve demand in the long-term [4–6]. As VREs become more prevalent, having sufficient flexible and peak capacity is essential for ensuring reliable power system operation [3]. Consequently, resource adequacy policy must leverage sufficient long-term investment in assets capable of fulfilling these operational requirements. Moreover, the unique cost structures of VREs affect short-term market dynamics, exacerbating existing concerns about the effectiveness of investment signals for ensuring long-term resource adequacy [4–6].

Against this background, three decades after reforms were first initiated to liberalise the electricity industry, many countries have embarked on a new wave of reforms to make their resource adequacy

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policy fit-for-a-low-carbon-system [1]. This often involves adjusting or introducing new capacity remuneration mechanisms (CRMs) that explicitly remunerate capacity for providing generation adequacy [6]. This transition is not merely a techno-economic process, but also calls into question legacy institutional structures, governance models, the roles of incumbent market players and traditional ideas on the roles of state and markets [1,5]. Yet, most literature is technical, or economics oriented, primarily focusing on how to design CRMs to enable cost-effective VRE integration, and overlooking the question of why countries adopt different approaches based on specific political economy contexts.

This paper contributes to the literature by examining recent resource adequacy reforms from a comparative, interdisciplinary perspective that considers the interplay of techno-economic, political, and institutional factors. Using a comparative political economy approach, it analyses the evolution of capacity remuneration mechanisms in Britain, Italy and California between 2013 and 2021. It answers the following research questions: how did differences in the techno-economic and political economy contexts of these jurisdictions affect their approaches to reforming resource adequacy policies to enable wider integration of VREs?

Findings highlight that the energy transition is bringing a reconfiguration of the political economy of the power sector involving increased state involvement in markets, even in traditionally liberal countries. Second, in line with claims made in the political economy literature, it demonstrates that recent reforms do not simply mirror the least-cost or most-efficient techno-economic solution. They are also heavily shaped by underlying institutional and market structures, the interests of key actors and their ability to influence final decisions in a process that is inherently political. The main implications for power sector governance are discussed in the conclusion.

2. Theoretical perspectives for understanding change in resource adequacy

2.1. Techno-economic implications of VREs for resource adequacy

According to economic theory, signals for long-term investment are conveyed through short-term market prices, which should allow investors to recoup their costs, while forward contracts and over-the-counter markets should help managing risk [ibid]. However, there are a set of ‘market failures’ traditionally plaguing the electricity sector [2,6,7]. The ‘missing money’ problem refers to the inability of investors to recover investment costs from price spikes in spot markets due the existence of low-price caps. Further, low liquidity in long-term markets often means that investors face high risk and high cost of capital, undermining the case for investment – the so-called ‘missing markets’ problem [ibid].

Economists highlight that these issues are exacerbated by VREs [4,8]. Compared to traditional power plants, wind and solar have very low marginal costs. As VRE shares increase, we tend to see lower and more volatile wholesale prices – the so-called ‘merit-order effect’ [2,4]. Implications are twofold: a reduction in conventional plants’ load factors and revenues, and in the incentives for future capacity investment [ibid]. Further, VREs are non-dispatchable, meaning their maximum output varies according to weather conditions creating a greater need for operational flexibility and peaking capacity [3,8]. These were traditionally provided by conventional plants and the transmission grid, but other solutions exist such as demand-side response (DSR), the aggregation of decentralised energy resources (DERs) and grid-scale batteries [ibid].

The ability of future power systems to cope with substantial VRE growth hence depends on appropriate incentives for flexible operation and investment being conveyed to a wide-as-possible pool of resources — i.e. rectifying missing market problems [2]. System operators procure system flexibility services and maintain reliability in real-time but

longer-term contracts might be needed to secure long-term capacity investment [ibid]. Capacity remuneration mechanisms (CRMs) refer to policies explicitly remunerating capacity (or load) to provide the proper level of resource adequacy [6]. Table 1 offers an overview of different CRM options.

Techno-economic studies analysed CRM designs across different geographies including Europe, the US, or conducting comparisons [2,3,5]. Though they shed light on the techno-economic implications of VREs identifying possible solutions, they do not fully explain why countries adopt different approaches. As observed by Leautier ([9]:364): “policymakers never fully embrace economists’ prescriptions [...] policymakers incorporate legitimate political concerns in electricity markets design.” Political and institutional conditions can contribute to more realistic explanations of recent change but are often overlooked. Hence, this paper expands the theoretical lenses into political economy and socio-technical literature.

2.2. Political economy, institutionalist and socio-technical perspectives

Political economy institutionalism is interested in the links between economics and politics within capitalist systems — i.e. the evolution of state-market relations, political struggles around the distribution of resources, and decisions on how to manage capitalism [10]. Typical assumptions include that states and markets are mutually constituted, markets are politically constructed, and that political economic systems undergo continuous evolutionary processes [ibid]. Within this tradition, different approaches emphasise different aspects of institutional formation, function, and change ranging from political interests, ideas, strategic behaviour to existing institutional constraints [11]. Related concepts are also found in socio-technical energy transitions theories seeking to explain patterns of technological change [12]. For example, *Technological Innovation Systems* [13] or the *Multi-level Perspective* [14] combine different categories of factors shaping energy transitions (e.g. technologies, economics and institutions) in co-evolutionary frameworks.

Most studies in these traditions focus on renewable energy policies, national energy transitions and liberalisation reforms, while piecemeal evidence exists on the political dynamics underpinning recent resource adequacy reforms. Table 2 summarises relevant categories of factors found to influence power sector change in existing research. Relevant to resource adequacy, governments tend to be risk-averse when it comes to resource adequacy as reliability events have major economic and political consequences [18,20]. Further, out-of-market mechanisms such as price caps and CRMs are often introduced to mitigate political risks associated with market power and price spikes [7,9]. The politics of resource adequacy were also found to be shaped by techno-economic ideas held by policymakers about the workings of power markets [19], the lobbying strategies of key market actors [20,21], institutional arrangements of key power sector agencies [18] and multi-level governance relations [22].

An interesting theoretical development seeking to explain recent reforms in the context of changing system conditions is the ‘hybrid markets’ perspective [23]. Its core argument is that, although many electricity systems have undergone liberalisation and we often refer to ‘power markets’, in practice, they are ‘hybrid regimes’ relying on a combination of market signals, regulatory interventions, planning, long-term risk sharing mechanisms [ibid]. However, these studies tend to provide functionalist accounts failing to capture political processes. With a few exceptions (e.g. [18,20]), the political economy of resource adequacy in the context of VRE integration remains mostly unexplored, especially from a comparative perspective. This study aims to fill this gap.

3. Conceptual framework and methods

To explain the evolution of recent reforms and operationalise the

Table 1
Typical characteristics of different types of CRMs [6].*

CRM	Description	Procurement model	Examples
Strategic reserve	A certain amount of additional capacity is contracted and held in reserve outside the energy market. The reserve capacity is only operated if specific conditions are met — e.g., a shortage of capacity in the spot market.	<ul style="list-style-type: none"> Centralised Volume-based Targeted 	Germany, Sweden, Belgium
Capacity payment	A central body sets a fixed price paid only to eligible capacity — e.g., selected technology types or newly built capacity.	<ul style="list-style-type: none"> Centralised Price-based Targeted 	Spain
Capacity market	The total amount of required capacity is set by a central body and procured through a central bidding process (auctions) determining the price. Two common variants of the central buyer mechanism include a simple capacity market and a reliability options design.	<ul style="list-style-type: none"> Centralised Volume-based Market-wide 	Britain, Italy, PJM, NYISO, Ireland
Capacity obligation	An obligation is placed on load-serving entities to individually secure the total capacity they need to meet their consumers' demand. Individual contracts between electricity suppliers and capacity providers are negotiated.	<ul style="list-style-type: none"> Decentralised Volume-based Market-wide 	CAISO, France, Australia

* Both Italy and Britain only recently transitioned to a capacity market, as analysed in this study.

Table 2
Political economy conditions identified through the abductive analysis and existing literature.

Categories	Specific conditions	Sources
National politics and government	<ul style="list-style-type: none"> Political ideologies, priorities and cycles Political acceptability of technologies and mechanisms Government incentives, capacity and effectiveness 	[1] [9] [15] [16] [17] [18]
Legacy state-market relations	<ul style="list-style-type: none"> Legacy political economy paradigm Dominant ideas on the role of markets Degree of restructuring, unbundling and privatisation 	[11] [15] [17] [18] [20] [21]
Sector-specific institutions (energy regulators and system operators)	<ul style="list-style-type: none"> Institutional cultures, missions and incentives Capacity, independence and policy influence Dominant ideas on mechanisms and technologies Legacy power market model and operational philosophies 	[9] [17] [18] [19] [20] [22]
Multi-level governance	<ul style="list-style-type: none"> Capacity, coordination and trust in multi-level institutions Dominant cultures and ideas in multi-level institutions Relations with neighbouring systems Regional political homogeneity, relations and balance of power 	[21] [22]
Market structures and interests	<ul style="list-style-type: none"> Market structures and ownership of key assets Economic composition of electricity demand Turnover and employment in energy sector Variety and organisation of interest groups Policy access and influence 	[11] [14] [15] [16] [18] [20] [21]

drivers of change, the analysis proceeded abductively. First, some overarching theoretical assumptions were developed drawing from political economy, socio-technical and economic theories [11,12,17]. Key conceptual constructs thus include techno-economic conditions (e.g. generation mix, electricity prices, capacity margins) and notions from political theory (e.g. interests, institutions and ideas) [ibid]. The core assumption is that these conditions co-evolve, thereby shaping the reform process. Based on existing studies of power system change, the political economy conditions expected to influence reforms were then operationalised in a set of key categories. As more data was analysed,

these categories were adjusted and refined until a final list was developed (see Table 2). Policy changes were analysed according to their defining characteristics including their stated objectives, scope of change, modifications in key design parameters, resulting policy trade-offs and technological choices [11,17].

A comparative in-depth analysis of three case studies (Italy, California and Britain) was conducted over an 8-year period (2013 to 2021). These cases were chosen because they have comparable system characteristics and VRE integration phases, levels of economic development and liberalised markets (Table 3). However, they exhibit important differences in legacy market structures, institutional and political settings (discussed in Section 4). The analysis drew on various sources of evidence including 134 documents, and in-depth interviews with 53 key power system stakeholders comprising of academics, sector experts, policymakers, market operators, and representatives of different energy companies and consumer groups (see Appendix A). Thematic coding proceeded abductively in a constant dialogue between theory and data (ibid).

4. Results by case study

4.1. Britain

4.1.1. Political economy context

Through the 1990s Britain had a centrally managed electricity pool with capacity payments [24]. The pool was the first step in the pioneering power sector liberalisation reform pursued by Margaret Thatcher's government as part of a wider agenda to limit state presence in the economy and break labour unions' power. During these years, generation and retail were fully restructured and privatised. In 2001, the pool was replaced by a self-dispatched energy-only market based on the principle that short-term markets would incentivise long-term investment [ibid]. Following liberalisation, market structures evolved towards the so-called 'Big Six' European utilities and some major independent power producers. In 2014, the Big Six supplied 70 % of total power

Table 3
Characteristics of cases.

	Britain	Italy	California
GDP (USD/capita)	48,711	44,140	66,661
Population (million)	66.4	60.4	39.5
Electricity demand (TWh)	326.9	315.8	284.4
VRE generation in 2014 (%)	10.7	13.5	12
Legacy capacity mechanism	Energy-only market	Capacity payment	Decentralised obligation

Databases: OECD; IEA; Energy Information Administration; California Energy Commission; Our World in Data.

output, and their portfolios were dominated by conventional generation – i.e. gas, coal and nuclear [20].

Traditionally, Britain has a liberal political economy model with a commitment to free markets, a centralised government structure, an effective and accountable civil service [25]. Since liberalisation, energy regulation has been under the regulator Ofgem,¹ which has high independence and technical capacity, while transmission was owned and managed by fully privatised system operator National Grid [24]. Until 2020, when the country formally left the European Union, the UK was part of EU single energy market, a regional effort to facilitate cross-border exchanges and harmonise market designs through increasingly prescriptive directives [interviews 28, 29]. Traditionally, the EU had preference for an energy-only market approach to resource adequacy [ibid]. When it comes to the way industry interests are negotiated, Britain exhibits a moderately corporatist system [25]. Mirroring a centralised market structure, British incumbents are well-organised, have significant resources, structural power, and policy access, while smaller market players traditionally play a limited role [20,21].

4.1.2. Techno-economic context

Fig. 1 illustrates installed generation capacity in relation to electricity peak demand on the British system. From 2010, the generation mix began transitioning from being dominated by conventional generation towards much larger presence of VREs [26]. In 2012, announcements were made for the retirement of 2GW of conventional generation, and it was estimated that a further 1GW would retire by 2015, mirroring low levels of profitability for gas-fired plants and uncertainties on future policies and market conditions [27]. It was predicted that VRE-growth in coming years would exert a further downward pressure on wholesale prices and load factors of conventional plants, thus resulting in lower capacity margins and less flexible capacity available for system balancing in the face of growing intermittency [interview 11]. In 2010, Project Discovery [28], an investigation into the future of security of supply by the regulator Ofgem, concluded that existing market arrangements were unlikely to deliver secure, sustainable, and affordable electricity in future years.

4.1.3. The British capacity market

In 2014, Britain saw a major shift in resource adequacy policy when it transitioned from an energy-only market to a capacity market (see Appendix B.1 for details on the mechanism's design). This was introduced as part of a sector-wide policy package, the Electricity Market Reform, alongside a new contracts-for-difference scheme for incentivising renewables, and a carbon price floor [29]. While the latter two

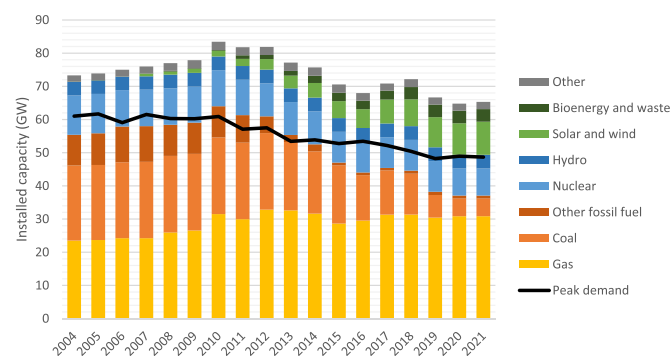


Fig. 1. Installed capacity and peak demand in Britain. Source: UK Government energy statistics.

mechanisms aimed to speed up decarbonisation, the CRM to ensure that long-term system security would be maintained as the power mix evolved [ibid]. Key events are summarised in Fig. 2 and discussed below.

Changes in techno-economic conditions and Ofgem's warnings (Section 4.1.2) were a major catalyst of change [interview 11]. Faced with the possibility that 'lights might go off' the government was compelled to introduce a mechanism that would act as a 'reassurance to the public' that system security would be maintained as it pursued deeper decarbonisation [interview 7, 1]. This represents a paradigm shift in dominant techno-economic ideas towards a recognition that short-term price signals are insufficient for maintaining long-term capacity adequacy in a high-VRE system [interview 2]. The market-led paradigm had played a central role in UK energy policy since the 80s, but now more public intervention became legitimised by two 'powerful strategic objectives': decarbonisation and security of supply [interviews 10, 3].

This shift encountered some resistance from within institutions: "there was blood on the floor of the board of Ofgem, two senior people resigned in protest because they basically felt Ofgem was abandoning the fundamental principles of competition as the primary aim of electricity regulation" [interview 1]. The reform also sparked a heated debate in the EU where the official position was an energy-only market albeit diverging views existed among member states [interview 29]. Eventually, the EU Commission approved² the British mechanism, which some argue was to avoid a political backlash: "the British government was lobbying hard and they [the Commission] didn't want to further inflame the sort of anti-European sentiments" [interview 1].

Nevertheless, market and competition principles continued playing an important role by informing the CRM design choice [interview 2]. When the decision on whether to adopt capacity market or a strategic reserve was being discussed, Ofgem firmly advocated in favour of the former mechanism because market-based and technology-neutral [interview 1, 14, 4]. Several observers note that the stance taken by the independent regulator was pivotal in determining the final decision [ibid].

Evidence also suggests that the policy process was heavily shaped by incumbent interests. Due to worsening economics for their conventional plants, most of these companies "advocated for explicit support" [interviews 12, 13]. Observers note how these actors contributed creating a sense of urgency by signalling looming capacity shortages, existing plant retirements and the withholding of future investment [interviews 3, 4, 5, 10]. Given the influence of British incumbents (see Section 4.1.1), policymakers were receptive to such 'missing money narratives' [20,21]. Existing research also suggests that, through their lobbying, conventional generators contributed to the selection of a capacity market design [ibid]. Hence, some observers go as far as saying that the mechanism was 'essentially a subsidy for gas-fired power generation', even though technological neutrality had been presented as a key reason for adopting this design [interviews 3, 4, 14].

Representatives of non-traditional providers such as DSR, batteries, aggregators and interconnectors argue that they faced unfavourable terms of access, especially in the early iterations of the mechanism [interviews 14, 18, 16]. They lament that key parameters were set in a way that did not account for their specific characteristics and undervalued their performance — e.g., high de-rating factors,³ long contract lengths⁴ and high penalties for non-delivery [21]. These groups were unable to match the resources of major incumbents, and hence their ability to shape the CRM design [ibid]. Further, policymakers' inexperience and uncertainties around the performance of non-traditional

² Member states need to present a case to the EU Commission to obtain State Aid approval.

³ These assign a de-rating value (in%) to the capacity contributions of resources based on availability.

⁴ Set at one-year for existing assets and 15-years for new built.

¹ Office of Gas and Electricity Markets.

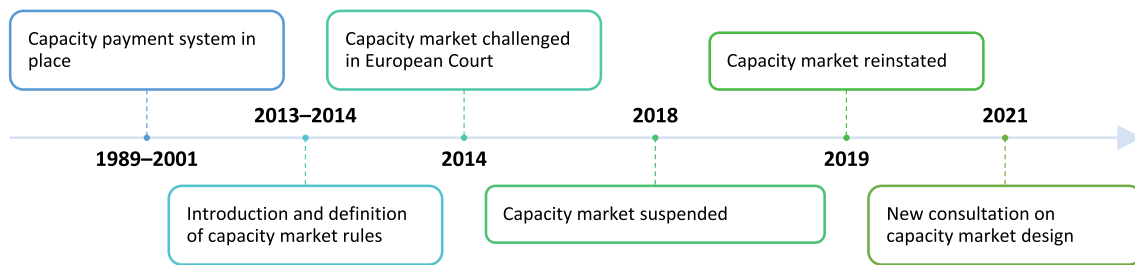


Fig. 2. Evolution of resource adequacy policy in Britain.

providers might have created a bias towards more conventional solutions [interviews 18, 19].

Fig. 3a illustrates the results of the first auction in 2014. 98 % contracts were assigned to existing capacity because low clearing prices⁵ did not encourage the construction of large new gas plants as originally intended ([30]; interview 17). Low prices were the result of market distortions caused by network charging rules disproportionately benefiting distribution-connected producers, which enabled small diesel generators to outcompete larger, more efficient gas plants [interview 6]. While existing gas was the most contracted capacity type, diesel and coal generators were awarded a sizeable portion of contracts causing ‘outrage’ among environmental groups and ‘embarrassment’ among policymakers as public money was used to subsidise the most polluting plants [interviews 14, 1].

Except interconnectors, participation by non-traditional providers in the first auction was almost non-existent. The DSR industry went ‘up in arms’ channelling considerable efforts into obtaining better terms of access [interviews 4, 18]. In 2014, DSR company Tempus Energy challenged the lawfulness of the British capacity market in the European General Court on the basis that it discriminated against DSR [21]. The Court ruled in their favour, auctions were suspended, and the government had to commit to modifying the scheme. According to participants, many perceived this as a ‘transgression on British sovereignty’ and was used as an example in the Brexit campaign [interview 1].

Later modifications aimed to widen participation of non-traditional providers and limit that of the most carbon-intensive generators [32]. These include a ‘controversial’ reform of network charges, the exclusion of coal from the capacity market and modifications in parameters regulating access for non-traditional providers [ibid; interview 6]. In 2021, auctions have seen no coal, limited diesel participation, supplanted by existing gas and a sizeable growth in interconnection capacity (Fig. 3b). While DSR and batteries made an initial market entry, their shares remain marginal, which these groups’ representatives argue is due to the persistence of unfavourable rules [interviews 16, 19]. Despite the removal of distortions, latest auctions encouraged a limited number of new gas plants as developers “face increasing challenges in attracting low-cost capital” [interview 8].

Despite its bumpy journey and shortfalls, the capacity market is generally seen as working by the industry as it offered financial relief to existing plants and “acted as a reassurance to opposition to renewables” by explicitly addressing potential resource adequacy risks that might emerge during the transition [interviews 2, 12, 13, 7]. The mechanism has seen incremental changes over time, but the fundamental structure remains unvaried. This might change as capacity investment is one of the key aspects being reviewed in the ongoing government’s Review of Electricity Market Arrangements (REMA) launched in 2022 [33]. A key aspect being considered is whether more explicit support should be introduced for investment in low-carbon flexible assets, particularly battery storage.

4.2. Italy

4.2.1. Political economy context

Italy’s power sector liberalisation started a decade after Britain’s and was externally driven by EU regulation [34]. Generation and retail were liberalised, but some key infrastructures remain partially state-owned. Italy’s market model is more physical than Britain’s with a semi-centralised dispatch⁶ and zonal pricing [ibid]. A capacity payment was introduced in 2004 as a temporary solution to growing reliability concerns following a major blackout⁷ in 2003 [Interview 25]. Wholesale market structures are characterised by the presence of two major partially state-owned utilities (Enel and Eni), several European and local utilities with varying sizes. In 2014, the six largest producers had a 50 % market share and a fossil-fuel dominated portfolio, especially gas, and some hydro [35].

Compared to Britain, a more government-dominated logic prevails here, government effectiveness is lower due to high political instability, the civil service has discrete technical expertise but is more exposed to political influence [36]. The Italian energy regulator ARERA⁸ was originally created with high independence and technical expertise, but over time there have been tensions with the government and political interference [interviews 20, 22, 25]. The system operator Terna, which owns and operates the transmission grid, is partially state-owned, has high capacity and expertise, but is sometimes criticised for lack of transparency [interviews 20, 22, 37]. Italy is part of the EU single energy market, which increasingly drives its national policy [interviews 21, 22, 31]. Since Italy’s market model differs from the standard EU design, further harmonisation sometimes requires ‘intense negotiations’ with the EU [ibid]. Italy has a highly corporatist system whereby interest associations are key for negotiating national policies [36]. The two former monopolies are often identified as particularly influential due to their ‘strategic role’ in the national economy [interviews 20, 22, 25]. Industrials also play a key role in the economy, are well-organised and engage in policy debates extensively sometimes in ‘adversarial tones’ with power producers [interviews 31, 37, 38, 22].

4.2.2. Techno-economic context

Up to 2012, reserve margins in the Italian power system kept increasing resulting in substantial generation capacity in relation to peak load (Fig. 4). Previous years had seen considerable investment in gas assets, further, Italy could rely on hydro resources, growing interconnection and renewable capacity [34,37,38]. Around 2012, reserve margins peaked with 130 GW of installed capacity servicing only 56 GW of demand [ibid]. However, this was predicted to change. Steep growth in renewables coupled with flat demand⁹ resulted in steep reduction in gas plants’ load factors. Between 2012 and 2016, 15 GW of old thermal power was decommissioned, and it was predicted that other 5 GW of

⁵ Around £19.40/kW/year compared to expectations of £49 kW/year [26].

⁶ I.e., unit-commitment and integrated scheduling of balancing and reserves.

⁷ Caused by an interconnector failure, it affected the whole country for 12 h.

⁸ Autorità di Regolazione per Energia Reti e Ambiente.

⁹ Related to a slowdown in economic activity following the 2009 crisis.

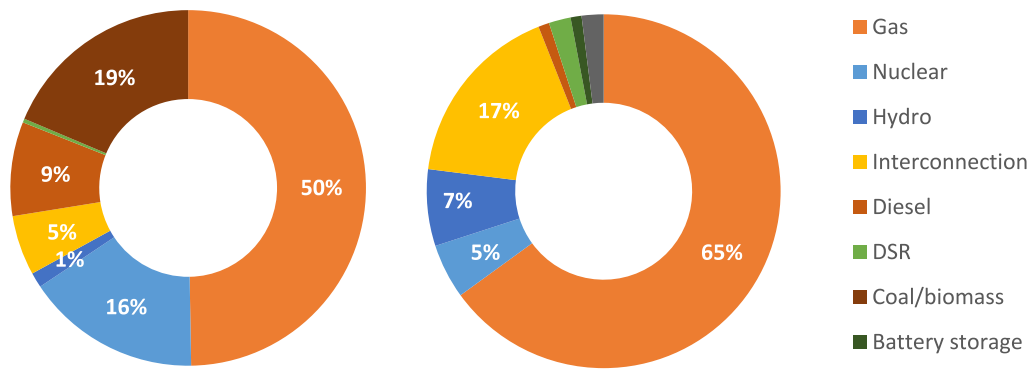


Fig. 3. Awarded capacity by technology — a) 2014 auction; b) 2021 auction [30,31].

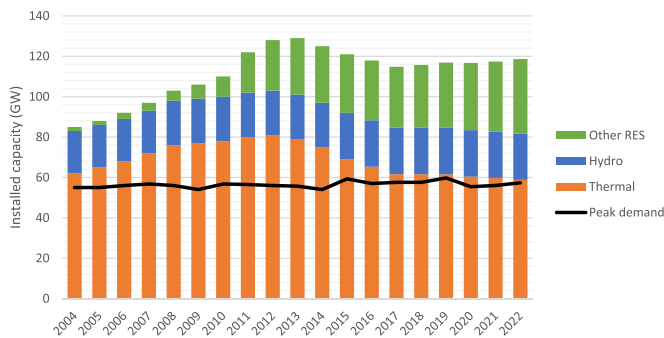


Fig. 4. Installed capacity and peak demand in Italy (GW). Source: Terna electricity statistics.

would be retiring in coming years [37]. The economics of newer plants were also affected, which had seen a major wave of investments in repowering and construction following liberalisation. Coupled with lower average prices due to the ‘merit order effect’ (see Section 2.1), this discouraged new investment contributing to ‘concerns around future system reliability’ [interviews 25, 30].

4.2.3. The Italian capacity market

In 2019, Italy’s legacy capacity payment was replaced by a capacity market (see Appendix B.2), marking an important change in resource adequacy policy [39]. The presented rationale was similar to Britain’s, that the mechanism would act as an insurance policy for system security during the energy transition and coal phase out, a support for struggling gas generators, a catalyser of new capacity investment and a price mitigator in energy and services markets [40]. Fig. 5 summarises key events, which are discussed below.

The conditions leading to the introduction of a capacity market in Italy somewhat differ from Britain’s. First, the decision to introduce a system-wide CRM in Italy dates further back to the 2003 blackout, which left behind a ‘culture of risk-aversion’ when it comes to resource adequacy [interviews 23, 26]. A capacity payment was introduced as a temporary solution in 2004. Since then, in the aftermath of liberalisation, Italy witnessed considerable gas investment contributing to a significant growth in capacity margins. These were considerably higher than in Britain when the capacity market was introduced. However, this left conventional producers particularly financially exposed to the demand drop at the end of the decade [interviews 34, 28, 37].

Mirroring this ambiguous techno-economic situation, the CRM debate lasted over 15 years: “there has been a back and forth of proposals between the regulator ARERA and Terna. Interest faded at times because they came to the realisation that there wasn’t a very urgent problem in terms of resource adequacy” [interview 29]. Terna, who is responsible for ensuring system reliability, conducted a resource

adequacy assessment in support of the mechanism, but withheld this information, which led some observers to condemn the system operator for ‘lack of transparency’ [38]. Another factor that contributed to such a long policy process is the short duration of Italian political cycles: “during this time we have had several governments with different positions on the capacity market” [interview 34].

Compared to Britain, the introduction of a capacity market in Italy represents a less radical shift in the political economy of the power sector. In fact, not only Italy had a pre-existing CRM, but is also historically more comfortable with state presence in the market (see Section 4.2.1). However, like Britain, by introducing a CRM Italy deviated from the dominant EU paradigm: “Europe had not yet made the conceptual step towards recognising the need for long-term contracts to encourage investment. There was still a persuasion on the efficacy of spot markets. [...] and a fear that long-term contracting might be configured as a state aid” [interview 28]. The Commission was particularly wary of the Italian mechanism fearing that “support would be targeted at state-owned generators” [interview 22, 23]. Following ‘many years of suffering and wars with Europe’ [interview 27], the Commission approved the mechanism after requiring several modifications to the original design, deemed an ‘overly explicit subsidy for fossil fuel generators’ [interview 23].

Decision-makers note that market and competition principles were key in informing the decision to opt for a capacity market with reliability options [interviews 27, 28]. The fundamental difference from a simple capacity market is that, instead of being fixed, the premium received by operators in exchange for their services is ‘linked to the wholesale market price’ [interviews 29, 21] (see Appendix B.2). If the wholesale price exceeds a certain threshold, operators must give back the price differential. While sometimes criticised based on complexity, proponents of this design stress that it is more market-compatible and better shields consumers from price spikes [interviews 27, 28].

Given Italy’s ambiguous resource adequacy situation, the introduction of a capacity market as a form of support for struggling gas generators is even more evident here with data pointing to the pivotal role of these interests in the policy process. Most fossil fuel generators including major incumbent Eni, advocated for the reform, constituting a strong coalition of stakeholders in favour [Interview 32, 34, 37]. Particularly keen was a group of medium-sized operators who had recently invested in new gas plants: “conventional generation suffered, and our company, who had contracted an important debt to build new power plants, faced the risk of not being able to meet the commitments made during the financing phase” [interview 34].

Interestingly, some note that, despite the significant presence of gas assets in its portfolio, Italy’s largest incumbent Enel exhibited a ‘mild stance’ on the capacity market, which they argue contributed to delaying reform as Enel’s opinion often constitutes a turning point

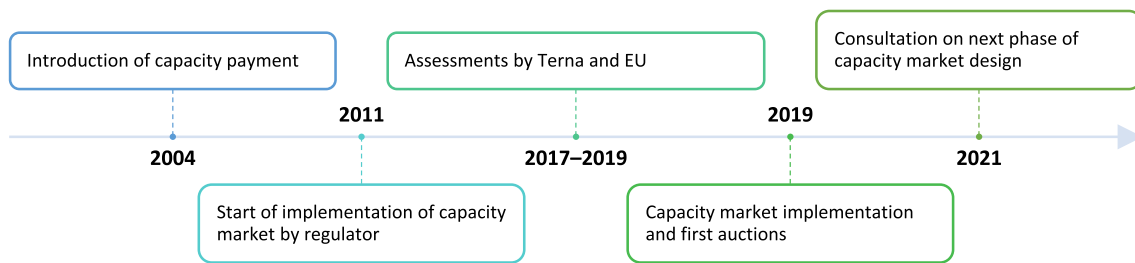


Fig. 5. Evolution of resource adequacy policy in Italy.

[interview 37]. Given Enel's influence within Assoelettrica¹⁰ and Italy's corporatist system (see Section 4.2.1), medium-sized operators formed Energia Libera, a new association with the capacity market as its 'workhorse' to advance their case [ibid]. A key narrative used by gas generators in support of the CRM was the fundamental role of gas in reliability, a 'sine qua non for the energy transition' [interview 33]. Like in Britain, gas producers contributed to creating a sense of urgency by signalling looming capacity shortages, the withholding of future capacity investment and plant retirements [Interviews 21, 33, 34].

Weak support or opposition to the CRM came from some residential consumer, environmental and DERs groups, which saw it as unnecessary and working against sustainability, affordability and decentralisation [41]. However, compared to gas producers, these groups have less influence in policy decisions (Section 4.2.1). Industrial consumers, who have much larger influence, did not have a strong position on whether a CRM was needed, however, they pressed for some key conditions in its design, specifically, the inclusion of price mitigation mechanisms (reliability options) and in the definition of price caps and floors¹¹ [interview 38].

Although the capacity market was supposed to be technology neutral, non-traditional providers including DSR, renewables, aggregators, batteries and cross-border generators argue they were excluded from participating [38,42]. They point to the same barriers as their British counterparts: low de-rating factors, excessive contract lengths and unfavourable rules on aggregation [ibid; interview 21]. Beyond these groups' limited policy influence, the conservative approach to valuing their assets can be understood in terms of legacy operational philosophies: "the Italian market is really physical. Terna's reasoning was I cannot see the single units, I cannot control the asset so I will set a low de-rating factor" [interview 21].

In the first auction of 2019, most capacity was assigned to gas generators, followed by hydro (Fig. 6), mostly existing capacity (95 %) [43]. This is despite extremely high prices for both old and new capacity,¹² and might be related to the ability of producers to exercise market power in a zonal market [interview 23]. There was no participation by DSR, aggregators and batteries mirroring unfavourable terms of access. In the 2022 auction, conventional generators continued to dominate, and clearing prices remained high [44]. Interestingly, there has been a modest increase in participation by cross-border generation and batteries (30 % of new built), while DSR's contribution remains marginal [ibid].

Overall, the Italian CM has fulfilled its primary objective, to support conventional operators, as consistently high prices have offered 'financial relief for existing plants' [interview 33, 34]. However, key design parameters remain fervently debated: conventional producers lament that the mechanism should become a 'more structural solution' [ibid], while non-traditional providers call for better terms of access [42]. As

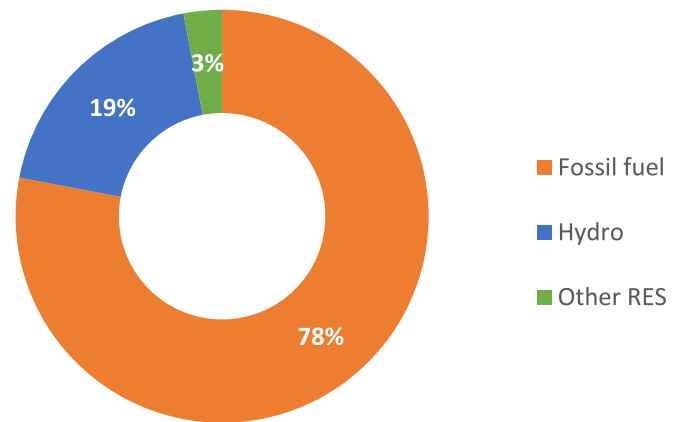


Fig. 6. 2019 auction — assigned capacity by technology [43].

put by one participant, "the Italian capacity market fundamentally doesn't satisfy anybody or a few" [interview37]. The industry is particularly concerned about the mechanism's ability to promote battery storage investment [Interviews 27, 28, 29, 32, 33]. Accordingly, "Italy has been fighting on the European front to secure the possibility of long-term remuneration" [interview 27 — senior regulatory official]. The EU recently recognised this necessity and Italy is currently in the process of defining a new mechanism [interview 29].

4.3. California

4.3.1. Political economy context

California first introduced a CRM in 2002 as a 'reaction' to the notorious Energy Crisis, a series of major blackouts that happened between 2000 and 2001, just after liberalisation had introduced a new regulatory regime prone to market manipulations [interview 47, 39, 40]. Hence, retail was never liberalised and remains under incumbent distribution utilities [ibid]. California's market is extremely physical with centralised security-constrained economic dispatch, energy and reserves co-optimisation and nodal pricing [interview 42]. Market structures are characterised by a mix of independent power producers with significant market shares, some major incumbent investor-owned distribution utilities, and several municipal public utilities [22]. Independent producers own most gas generation, incumbent utilities retain nuclear and hydro resources, while there are many small solar producers [interviews 39, 49].

The crisis deeply shaped California's governance approach: "we tried markets, and we failed so people went the other way to really have much more control and make sure this never happens again" [interview 47]. Resource adequacy is under the jurisdiction of the California Public Utilities Commission (CPUC), a powerful state agency with a 'strong political mandate' [interviews 46, 45, 43]. Beyond the CPUC, California's governance is complex with a plural executive, multiple agencies, and local public power [15]. The system operator CAISO operates transmission and power markets without owning transmission.

¹⁰ Now Elettricità Futura, is the largest and most influential association representing the Italian power sector.

¹¹ These set limits to the premium received by generators.

¹² €33/kW for existing capacity and €75/kW for new capacity [40].

Its board is appointed by the Governor,¹³ a legacy of the crisis, though it is regulated at the federal level [22]. State institutions are ‘weary’ of the federal regulator FERC,¹⁴ which was never able to impose a US standard market design [interviews 40, 45]. Due to a perception that FERC failed to intervene adequately during the crisis, California’s ‘resource adequacy program was structured to avoid federal regulation’ [interview 42]. CAISO manages the single Western Energy Imbalance Market, a regional trading platform with a complex joint-authority governance structure [22]. California’s interest groups are numerous and competitive, mirroring a highly pluralist, polarised political landscape and a market undergoing fragmentation [15]. Beyond large producers and incumbent utilities, there are influential environmental, local and decentralised energy groups [interview 41].

4.3.2. Techno-economic context

Fig. 7 illustrates California’s installed capacity in relation to electricity peak demand. From 2010, the generation mix began transitioning from being dominated by conventional generation towards much larger presence of VREs resulting in a period of low prices that challenged gas plants economics: ‘independent producers and merchant generation were suffering, relatively new combined cycles that didn’t plan retiring were going through bankruptcies’ [interview 50]. About 5 GW of old gas facilities reaching the end of contracts were expected to retire, and retirements of conventional generators (i.e. coal, nuclear and once-through-cooling plants) were also actively pursued by state policy [45]. In 2014, the CPUC predicted that most coal, once-through cooling and nuclear capacity would retire by the next decade, including Diablo Canyon servicing around 9 % of the state’s supply [ibid].

Meanwhile, California became increasingly reliant on out-of-state resources for reliability [interviews 42, 44, 48, 50]. Surrounding states historically had abundant hydro and coal resources but, from 2015, due changing weather patterns and coal retirements, it became clear that imports would not be able to fill the gap left by in-state retirements [ibid]. The state was also increasingly reliant on solar resources, whose output is however highly correlated [ibid]. From 2017 ‘capacity shortages became very evident’ [interview 50]. Coupled with more frequent extreme weather, this caused California to have ‘lots of close calls from a reliability perspective’ [interview 48]. Particularly noteworthy are the August 2020 outages when extreme heat drove demand up that could not be met by available resources [46].

4.3.3. California’s decentralised obligations scheme

California’s decentralised obligations scheme has two main mechanisms: a long-term resource plan, submitted by load-serving entities¹⁵

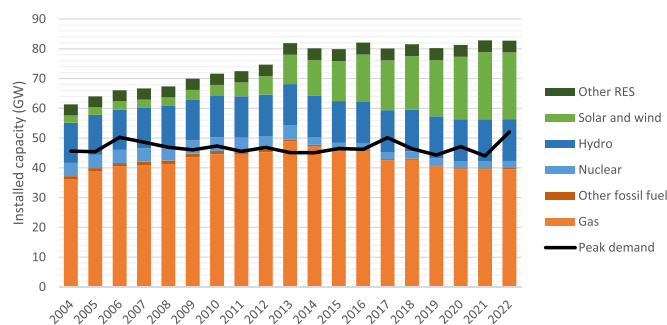


Fig. 7. Installed capacity and peak demand in California (GW). Source: CEC energy data.

¹³ Confirmed by the Senate, based on nominations from a stakeholder process.

¹⁴ Federal Energy Regulatory Commission.

¹⁵ I.e. entities acting as electricity retailers required to deliver on the obligations.

and approved by the CPUC to ensure adequate long-term capacity investment; and shorter-term local and system requirements requiring load-serving entities to procure enough capacity on a monthly and yearly basis to maintain reliability in the operational timeframe [46,47] (see Appendix B.3 for a full description). Traditionally, incumbent utilities acted as the main load-serving entities, but the recent growth of new retail market actors¹⁶ fragmented the responsibility for delivering on obligations [48,49].

While the basic structure of California’s legacy obligations scheme remains unvaried, since 2013, its ‘rules have been in constant flux’ [interview 48]. For example, the methodologies used by the CPUC for determining local and system reserve margins and the capacity values of different resources have evolved over time, as well as long-term resource procurement targets [46,47]. Up to the end of the decade, the state’s primary focus was on decarbonisation, but significant changes in its generation mix and market structures, and a series of extreme system events have recently determined a policy shift with a stronger focus on system adequacy and reliability. Key events are summarised in Fig. 8 and discussed below.

Techno-economic conditions only partially explain California’s approach to resource adequacy. Up to the mid-2010s, despite signs of future reliability issues (Section 4.3.2), the state continued pursuing conventional generator retirements [interview 50]. Only following extreme system events, it made a policy U-turn, as discussed later in this section. This seems to contradict a wide-spread assumption that governments are risk-averse when it comes to resource adequacy and can be explained through California’s exceptional political commitment to decarbonisation, which some describe as ‘bordering on the religious’ [interview 43].

One of CPUC’s first steps towards tackling emerging reliability issues was introducing explicit flexibility requirements in 2014, which must be met by load-serving entities when procuring capacity for short-term reliability [50]. Further, in the same year, new long-term targets mandated load-serving entities to contract 1325 MW of battery storage by 2020 [51]. This mirrors California’s ambition to become a ‘leader’¹⁷ in the procurement of low-carbon reliability capacity [interviews 40, 42], pointing to a techno-economic culture open to experimentation and a willingness to absorb innovation costs [interviews 43, 41, 39]. Further, it reflects California’s traditional easiness with planning system outcomes, which is rooted in its liberalisation history (see Section 4.3.1): ‘as they always do in California, they put a burden on the utilities to go and contract for storage. [...] It was the visible hand, not the invisible hand that did that’ [interview 40].

By the end of the decade, growing concerns around reliability and market fragmentation¹⁸ led the CPUC to consider more radical changes, specifically, a move towards a more centralised procurement [49]. Among the options considered for a new mechanism was a CAISO-led capacity market, which would have drawn California’s approach nearer to Britain and Italy’s. Eventually, the CPUC centralised procurement under incumbent utilities, a limited change from the pre-existing model [ibid]. Evidence suggests that this decision can be attributed to three main factors: institutional relations across layers of governance, legacy market structures and stakeholder interests.

Decision-making institutions (i.e. CPUC and the California Energy Commission) opposed a CAISO-led capacity market fearing that this would ‘open state policy to federal jurisdiction’ [interview 41] as transmission-wide activities are regulated by FERC. As noted in Section 4.3.1, California’s institutions exhibit a deep-rooted mistrust of FERC

¹⁶ Community choice aggregators are programs allowing local governments to procure power on behalf of local consumers. They served 25 % of peak load in 2020 [48].

¹⁷ California had 4.2 GW of installed storage capacity in 2019 [51].

¹⁸ I.e. an increase in instances when load-serving entities were unable to meet obligations, especially smaller retailers [48].

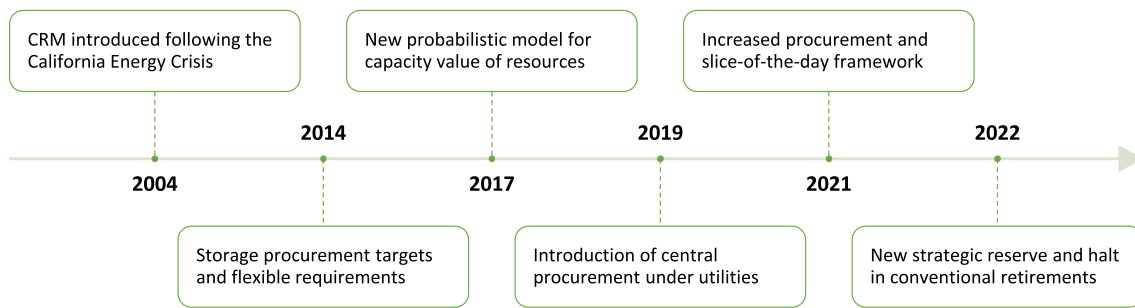


Fig. 8. Evolution of resource adequacy policy in California.

dating back to crisis. They also fear that ‘giving up control’ over key policy areas would expose them to fluctuations in federal politics ‘undermining state decarbonisation efforts’ [interviews 45, 48, 41]. Consultation documents reveal that the capacity market had found strong support among independent power producers who own most gas assets [49]. In 2018, they had even made a case that FERC should mandate a capacity market in California on the basis that “current arrangements prevented reasonable returns on their investments” [52]. However, these producers’ repeated calls never took hold. This perhaps reflects their limited influence in the context of such fragmented and pluralist landscape (Section 4.3.1), especially if their position diverges from that of a powerful coalition composed of the CPUC and the main consumer groups [49].

Up to 2020, California made different technological choices from the other two cases by actively pursuing the retirement of conventional generators (nuclear and gas) without incentivising new plants [interviews 39, 50, 47]. Instead, it directed its efforts to maximising battery storage procurement.¹⁹ Beyond a strong political commitment to phasing-out fossil fuel generation, this can be explained through the strong opposition faced by conventional plants among local environmental groups and communities ‘concerned about local ecosystems’ [interviews 52, 47, 50]. While in the other two jurisdictions conventional generators formed a strong coalition able to shape the direction of policy, their Californian counterparts were unable to do so mirroring a more fragmented market and a pluralist interests’ landscape (Section 4.3.1).

While VREs were not procured as capacity product in the other systems, for years, solar reliability contribution was highly valued in California, despite the high correlation in generation output [interviews 44, 50]. According to several participants, the rationalisation of solar capacity contributions took several years due to strong opposition from the state’s ‘powerful solar industry’ [interviews 49, 43]. Eventually, in 2017 a new statistical method²⁰ was introduced that reduced solar capacity value by approximately 80 % [47].

Like their Italian and British counterparts, California’s DSR and DER aggregators argue that the reliability value of their services remains unappreciated [interviews 51, 52]. Some experts note how DSR’s past underperformance contributed to a perception that these are not a ‘viable solution’ compared to other resources [interview 44]. For their part, decentralised energy advocates argue that both incumbent utilities and independent power producers have openly been opposing their business models, perceived as ‘risky’ and a ‘threat to incumbent market positions’ [interviews 46, 52].

Fig. 9 shows the resources committed local and system plans for 2019. Despite the state’s efforts to phase out conventional generation, gas comprised a sizeable portion of contracted capacity. This was

followed by hydro, DSR, CHP and solar.

A major push to change adequacy requirements came in the aftermath of 2020 blackouts. First, the CPUC mandated the procurement of additional capacity, increasing procurement reserve margins and storage long-term targets [53]. Second, there was a policy U-turn in conventional plant retirements, including Diablo Canyon nuclear plant, a decision that would have been ‘unthinkable ten years ago’ [interview 39]. Several gas plants meant to retire were contracted in a new strategic reserve scheme procuring emergency generation for times of system stress [53]. Critics argue that this was a costly approach: “we probably moved a little too fast with the retirement of baseload generators and now [...] they’re panicked so we are going to spend billions of dollars for getting electricity for 60 hours” [interview 47]. This decision outraged environmental groups who see it as ‘working against decarbonisation’ [interview 52].

The CPUC also introduced major modifications in system capacity requirement methodologies [54]. In contrast to the legacy framework setting single capacity requirements each month based on monthly peak load, a new ‘slice-of-day’ framework will set hourly obligations for a representative day in each month, determined using the load profile for the ‘worst day’ (i.e. with the highest peak load) [ibid]. The framework also includes new methodologies for computing RES reliability contributions²¹ and sets specific requirements²² to optimise storage operation. This represents a shift in the techno-economic logic underpinning capacity procurement towards more explicit consideration of peak system needs and specific assets’ performance. While generally welcomed by the industry given its simplicity, some argue this is a ‘step into uncharted territory’ as this design was never implemented elsewhere [interview 48].

5. Comparative analysis

All jurisdictions implemented important modifications to their resource adequacy policy in response to changing system conditions. While there are common trends, there are also important differences in the scope of these changes, mechanism design choices, resulting policy trade-offs and technological outcomes. Table 4 characterises recent reforms along these key dimensions, while the next sub-sections discuss the conditions that were found to shape the reform processes. These are also reported in Table 2 in relation to existing literature.

5.1. Techno-economic conditions

As the three jurisdictions undertook deeper power system decarbonisation, they experienced similar techno-economic challenges. As predicted in the techno-economic literature (Section 2.1), VREs led to lower and more volatile wholesale prices, contributing to what

¹⁹ In 2019, an additional 3300 MW of capacity was mandated by 2023.

²⁰ The Effective Load Carrying Capability (ELCC), a probabilistic measurement of a resource’s ability to generate when the grid is most likely to experience shortfalls [47].

²¹ Now based on historical hourly production profiles instead of the legacy probabilistic method.

²² I.e., that enough capacity is available to charge before discharging.

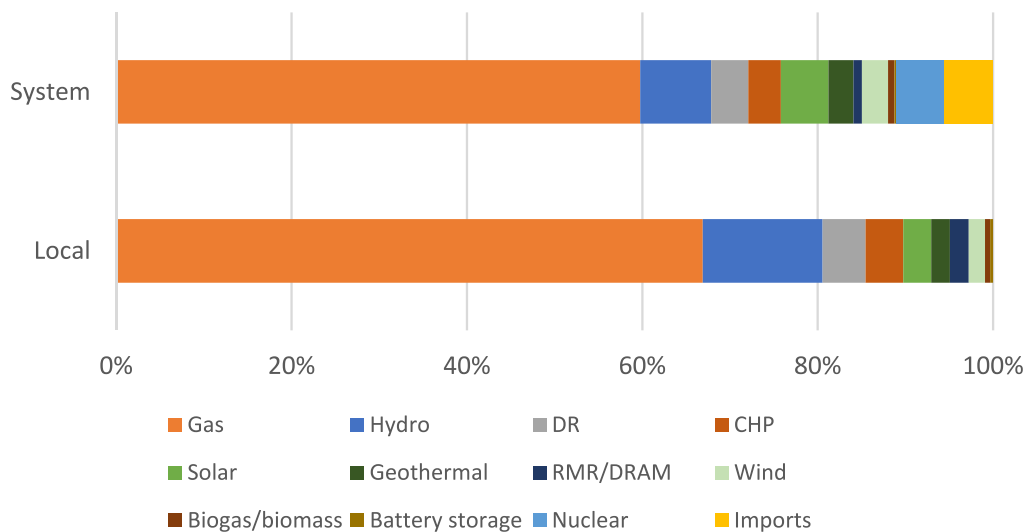


Fig. 9. Yearly resources set in month-ahead plans for system and local requirements. Source: 2019 CPUC Resource Adequacy Report.

Table 4
Summary of change.

	Britain	Italy	California
CRM design evolution	Significant shift from energy-only market to a capacity market in 2014.	Shift from capacity payment to a capacity market with reliability options in 2019.	From 2014, significant modifications to legacy decentralised obligations scheme — i.e. procurement model methodologies, targets.
Reform(s) objectives	Ensure future system reliability in the context of higher VRE shares and coal phase out, and support struggling gas generators.	Ensure future system reliability in the context of higher VRE shares and coal phase out, support struggling gas generators, mitigate prices in energy and services markets.	Different objectives over time: maximising procurement of low-carbon reliability, respond to market fragmentation and steep increase in reliability challenges.
Policy focus	From cost and competition to decarbonisation and system reliability.	From cost and competition to decarbonisation and system reliability.	From mainly decarbonisation to decarbonisation and system reliability.
Technology choices	Mainly supported conventional generation (gas, hydro nuclear) and interconnectors, marginal but growing participation of battery storage and DSR.	Mainly supported conventional generation (gas and hydro), marginal but growing participation of cross-border resources and battery storage.	Conventional plant retirements, gradual shift away from VREs for reliability. Supported battery storage but limited participation of other non-traditional providers.

economists call the ‘merit-order-effect’. Coupled with flat demand, this undermined gas generators’ economics leading to a wave of retirement announcements. Over the 2010s, technical projections pointed to a future decline in capacity margins and a halt in new capacity investment across all jurisdictions, who faced the prospect of relying on an increasingly intermittent pool of resources for future reliability. Eventually, this led all jurisdictions to review their resource adequacy policy.

However, the significance of the reliability challenges faced by the three jurisdictions and their policy responses present important differences. Britain decided to introduce a CRM in the early 2010s, when the system apparently had adequate capacity margins, but these were declining sharply due to announced retirements. Around the same time, Italy initiated discussions on the CRM, when the system reached an overcapacity peak, but missing markets issues were emerging — an ambiguous techno-economic condition that partially explains delays in reform. In the 2010s, California moved swiftly with conventional plant retirements, and in the following years, saw a steep reduction in capacity margins. More drastic resource adequacy measures only came in the aftermath of significant reliability events, made more frequent by changing weather patterns. While important, techno-economic conditions cannot fully explain the timing of jurisdictions’ responses in relation to emerging reliability challenges nor their decisions in terms of mechanism designs and approaches to valuing different technologies.

5.2. Political economy conditions

5.2.1. National politics and government

In line with previous research [15,18], the approaches taken by the jurisdictions can be partially explained in terms of the evolution of national political priorities and government incentives. The literature tells us that governments tend to be risk-averse when it comes to resource adequacy, as blackouts are particularly damaging politically [7,9]. This seems to apply well to Britain and especially Italy where the prospect of decreasing reserve margins and future reliability problems compelled governments to support conventional generators as a political reassurance for a ‘safe’ energy transition. However, while in GB CRM implementation was swift, Italy saw an 8-year policy process with a back and forth of proposals mirroring frequent changes in government.

On the other hand, California’s initial approach has been to aggressively pursue conventional generators retirements maximising low-carbon reliability procurement, even with the prospect of future reliability issues. Only when these materialised, did the state make a significant policy U-turn. This seems points to a different balance of trade-offs across reliability and decarbonisation across cases, with Californian institutions exhibiting a uniquely strong political commitment to being a decarbonisation leader even if that involves absorbing some risk.

5.2.2. Legacy state-market relations

The fact that all jurisdictions implemented a CRM in response to changing system conditions substantiates arguments in the ‘hybrid markets’ literature that the need to undertake the energy transition

while ensuring resource adequacy can alter state-market relations even in traditionally liberal countries [23]. However, differences in the liberalisation histories, legacy ideas around the role of markets and industry structures determined different approaches to designing CRMs and battery storage procurement [16,17,20].

By transitioning from an energy-only market to a CRM — along with other changes in the EMR, Britain underwent the most radical shift in the political economy of the power sector. This was underpinned by an intellectual struggle within decision-making institutions over what was perceived by some as abandoning market principles. In Italy, the CRM represents a more moderate shift as the state historically maintained a discrete level of control over the power system. Nevertheless, both countries have fully liberalised power markets and are historically committed to market principles, which continued to play an important role in the selection of the capacity market design. Since the energy crisis, the CPUC retained a higher degree of control over system planning, and retail and the delivery of state programmes remain organised around incumbent distribution utilities. Early on, the CPUC's explicitly mandated the procurement of specific technologies (i.e. battery storage) to incumbent utilities.

5.2.3. Sector-specific institutions [5.2.3]

Evidence also suggests that the characteristics and actions of key power sector institutions are relevant to understanding policy responses, especially in terms of their cultures, independence, and influence over national policy [18]. The British regulator and Italian system operator Terna played a decisive role in setting the case for change and shaping the design of CRMs. CAISO's mission is also to maintain system security; however, its unique institutional design means that 'CAISO is not in the driver seat when it comes to resource adequacy' [interview 50], instead, it closely follows state policy (and politics), which prioritised decarbonisation over other considerations.

Findings also points to the importance of cultures and operational philosophies of these institutions to explaining technological choices [19]. In all jurisdictions, uncertainties around the performance of non-traditional providers resulted in a conservative approach to valuing them albeit with important differences. For example, the Italian operator exhibits a particularly conservative attitude towards assets that it cannot control directly including cross-border capacity, more widely procured for reliability in the other systems.

5.2.4. Multi-level governance [5.2.4]

Evidence suggests that institutional arrangements and relations across layers of governance are also important to understanding recent reforms [22]. Broadly, evidence points to the existence of important political tensions between national and supranational institutions due to a resistance to 'giving up control' over an extremely strategic policy area. This is most evident in California, where national institutions resisted the introduction of a capacity market, which would have opened state policy to federal jurisdiction and politics. This reflects the existence of historical institutional tensions and ideological differences between California and other US states [15].

By introducing a CRM, both Italy and Britain deviated from the EU preference for an energy-only-market model. The EU position was based on competition principles (i.e. fears that national subsidies might create unfair advantages for national producers) and a belief that short-term markets can deliver adequate capacity investment. However, in practice, different visions exist among member states: "there is a certain group of countries in the centre of Europe with the ability to increment cross-border transfers who are strongly against CRMs while [...]. Countries with more structural constraints are favourable [to CRMs] such as Italy, Spain and the UK who have an interest in developing national resources" [interview 29]. Hence, the EU position is also likely to reflect the balance of power among member states with different preferences. Both in Britain and Italy, national institutions engaged in intense negotiations with the EU and had to demonstrate the need for

CRM before receiving approval. From its side, the EU had to strike a difficult balance: making sure these mechanisms do not undermine competition in the single market without fuelling anti-European sentiments that might undermine further regional integration.

5.2.5. Market structures and interests [5.2.5]

The evolution of resource adequacy policy was found to be heavily influenced by some key interest groups, whose ability to influence policy varied across cases based on legacy market structures and the wider political environment [15,18,20,21]. Debates focused on overall mechanism designs as well as the specific parameters determining the reliability value of different resources. Broadly, evidence points to opposing positions on these issues between incumbents (utilities and conventional generators) and DSR, RES and decentralised energy groups, albeit these political dynamics are much more nuanced in practice.

Incumbent conventional generators strongly influenced the CRM design selection in both Britain and Italy. Reflecting centralised market structures, these producers formed a powerful coalition with a strong preference for a capacity market and were able to influence policy through threats of plant retirements, using interest associations and deploying narratives strategically. The Italian and British CRMs were designed to support existing conventional capacity and had unfavourable terms of access for non-traditional providers with less policy influence. Reflecting their economic importance, Italian industrials were more involved in the policy process and were able to impose some conditions in the mechanism's design.

In California, repeated calls to introduce a market-wide mechanism by independent producers never had the same leverage, reflecting a more variegated and pluralist interest group landscape, ongoing market fragmentation. Plant retirements also mirror political opposition by powerful local environmental groups. Further, the relative influence of interest groups also explains why California attributed large reliability value to solar producers, who are well organised and resisted changes to the mechanism.

6. Discussion and conclusion

This paper analysed the recent evolution of resource adequacy policy from a comparative, political economy perspective. In doing so, it contributed to a growing body of evidence showing that the evolution of energy systems is not merely shaped by logics of techno-economic optimisation, rather, by the interactions of techno-economic and political conditions. As they transitioned to a greener power mix, all jurisdictions faced techno-economic challenges that acted as a major catalyst of change. However, reform processes were also heavily shaped by national political priorities, sector-specific institutions, historical state-market relations, multi-level governance arrangements and the interests of key stakeholders.

There is a noticeable convergence towards market designs that combine short-term markets for efficient dispatch with capacity remuneration mechanisms for long-term resource adequacy. This suggests that CRMs have come constitute an inherent feature of power market design rather than a temporary fix: "as you start to put more renewables on, you ask the question about energy security, and you inevitably end up with capacity markets or some other form of intervention" [Interview 7]. This in turn challenges legacy state-market relations in the power sector with 'hybrid markets' emerging as the new norm even in jurisdictions historically most committed to free-market principles [23].

Achieving a balance between market dynamics and government coordination is thus essential in an increasingly decarbonised, complex, and volatile energy landscape. Ultimately, this equilibrium depends on the unique context of each jurisdiction. Decisions about market design extend beyond techno-economic optimisation and involve considerations of legitimacy, political struggles, and acceptable policy trade-offs within a specific context at a given time. Regardless of the chosen model,

policymakers should strive for coherence through appropriate integration of long-term and short-term mechanisms.

Efforts should also be directed towards establishing coherent, well-coordinated, and adaptable governance arrangements that align with emerging market designs. Traditional roles of power sector institutions, narrowly focused on ensuring well-functioning markets, may need to be reformed to accommodate these changes. Additionally, states face the politically difficult question on the right balance to strike between achieving further multi-level governance coordination and system integration, and retaining control over key decisions.

In a 'hybrid market', price signals cease to be the only force driving the short- and long-term behaviour of market players and, hence, system evolution. The design of contracts is a key factor in driving investment decisions in different technologies. The negotiation of who can access which contracts at which conditions, is a fundamental area of contestation where winners and losers are made ex-ante. This calls for a reflection on whether existing governance processes enable participation by new technologies and providers alongside incumbents, and how their relative ability to influence decisions is reflected in the final design of CRMs. Findings also point to the importance of legacy techno-economic ideas in driving key decisions, which in turn should encourage decision-makers to question their assumptions to allow for the emergence of innovative approaches.

All of this has important implications for the definition of future technological pathways and their potential to deliver on key policy objectives (e.g., reliability, affordability, and decarbonisation). In fact,

the benefits of diversifying the capacity mix are magnified in a high-VRES system as too much reliance on a limited range of technologies and providers might have serious reliability and cost implications. The Californian experience also shows that, as climate change effects begin to be felt, power systems might also have to withstand more disruption.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

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Appendix A. Data collection and analysis

The triangulation of document and interview data was used to increase findings' reliability and cross-check of information to mitigate bias. The focus was on evidence offering insights into recent technical, market and policy developments, as well as the interests, motivations, interactions of key stakeholders, the underlying institutional environment and key implications of policy change. Analysed documents, their uses and an estimate by case are reported in [Table A.1.1](#).

Table A.1.1
Collected documents and uses.

Source type	Information extracted	GB	IT	CA
Key organisations' webpages	Missions and interests, history of organisation, activities, institutional structures and governance processes, rules and policy changes, policy/political priorities and techno-economic ideas	3	7	6
Official policy and consultation documents	Policy/political objectives and priorities, rules and policy changes, drivers of reform, policy processes, techno-economic ideas, policy trade-offs and implications, technological choices	10	6	13
Media publications and statements	Rules and policy changes, drivers of reform, key debates, interests and preferences of key stakeholders, policy trade-offs and implications, technological choices, power relations and policy influence	1	4	9
Interest groups' publications and consultation responses	Interests and preferences of key stakeholders, key debates, techno-economic ideas, policy trade-offs and implications, technological choices, power relations and policy influence	0	4	3
Technical reports by key institutions	Evolution in key techno-economic conditions, rules and policy changes, drivers of reform, implications of policy change	15	9	5
Grey and academic literature	Evolution in key techno-economic conditions, rules and policy changes, drivers of reform, policy processes, institutional structures, policy/political priorities and techno-economic ideas, policy trade-offs and implications, technological choices, interests and preferences of key stakeholders, key debates, power relations and policy influence	14	9	16
	Total	43	39	52

53 interviews with key power system stakeholders were conducted between October 2021 and June 2022 ([Table A.1.3](#)). Sampling was purposive and pre-stratified according to relevant categories of stakeholders found in the literature to maximise the variety of views. However, collected interviews differ from this pre-determined sample, which is not perfectly balanced across stakeholder categories and cases (see [Table A.1.2](#) for a comparison). This is partially related to issues of access, but also because the researcher collected data considering information that became available from documents until the point of saturation, whereby new evidence did not yield additional information. Many interviewees covered multiple roles over time or were involved in policy processes thus offering the needed information.

Table A.1.2

Expected interviews vs actual sample.

Participants	Number * cases (expected)	Total achieved	GB	IT	CA
Academics and experts	3 * 3 = 9	16	5	7	4
Consultants involved in policy process	2 * 3 = 6	5	1	2	2
Policymakers and officials at regulators	3 * 3 = 9	7	4	1	2
System operator representatives	1 * 3 = 3	3	1	1	1
Representatives of incumbent utilities and producers	3 * 3 = 9	10	3	5	2
Representatives of renewable energy producers	1 * 3 = 3	4	2	1	1
Representatives of new flexibility providers and decentralised energy solutions	2 * 3 = 6	4	2	0	2
Representatives of consumer groups	1 * 3 = 3	1	0	1	0
Financial investors	1 * 3 = 3	2	1	0	1
Other		1	0	1	0
Total	51	53	19	19	15

Participants were identified ex-ante based on internet sources, publications, conferences, the researchers' network and, in later stages, by snowballing. During the interview, were asked to discuss recent developments in electricity markets design, drivers and dynamics of policy change, the role of key actors and institutions, and their visions for future developments. Interviews were semi-structured and in-depth with extensive use of follow-ups to allow new topics to emerge. Data was collected in compliance with UCL ethical guidelines.

Table A.1.3

Interviews conducted.

N.	Participant role at the time of reform	Case
1	Energy economist	Britain
2	Energy economist	Britain
3	British energy policy expert	Britain
4	British energy policy expert	Britain
5	British electricity market design expert	Britain
6	Electricity market design consultant	Britain
7	Senior policymaker	Britain
8	Senior policymaker	Britain
9	Senior policymaker	Britain
10	Senior official at regulator	Britain
11	Senior market expert at system operator	Britain
12	Representative of major incumbent generator	Britain
13	Representative of major incumbent generator	Britain
14	Representative of renewable energy industry	Britain
15	Representative of renewable energy industry	Britain
16	Electricity storage asset management expert	Britain
17	Energy trader at medium-sized operator	Britain
18	Representative of decentralised energy industry	Britain
19	Representative of non-traditional flex provider	Britain
20	Energy economist	Italy
21	Energy economist	Italy
22	Energy economist	Italy
23	Resource adequacy expert	Italy
24	Technical expert in power system technologies	Italy
25	Italian energy policy expert	Italy
26	Power sector journalist	Italy
27	Senior official at regulator	Italy
28	Senior market expert at system operator	Italy
29	Government consultant	Italy
30	Government consultant	Italy
31	Representative of major incumbent generator	Italy
32	Representative of major incumbent generator	Italy
33	Representative of major incumbent generator	Italy
34	Representative of gas generator	Italy
35	Representative of major RES producer	Italy
36	Representative of power sector industry	Italy
37	Representative of medium-sized generators	Italy
38	Representative of industrial consumers	Italy
39	California energy policy expert	California
40	Energy economist	California
41	Energy politics expert	California
42	Electricity market design expert	California
43	Energy regulation consultant	California
44	Representative of system operator	California
45	Senior official at energy regulator	California
46	Senior policymaker	California
47	Government consultant	California
48	Representative of large incumbent generator	California
49	Representative of wind industry	California
50	Electricity investment banker	California
51	Representative of distributed generators	California

(continued on next page)

Table A.1.3 (continued)

N.	Participant role at the time of reform	Case
52	Advocate of local energy systems	California
53	Representative of local utility	California

Collected data (all interviews and the most relevant documents) was thematically analysed through Nvivo. The coding approach was abductive in that it combined a provisional list of codes developed beforehand (to align coding with the conceptual framework) with data-driven coding to enable flexibility. As more data was coded, provisional categories were adjusted using an eclectic coding strategy and by clustering codes according to commonalities, regularities and variation to generate a smaller and more focused set of themes. The information extracted through coding was then analysed through a range of focusing strategies to highlight key relationships (e.g. matrixes, hierarchies, taxonomies) and compared with existing theory.

Appendix B. Design of capacity remuneration mechanisms

B.1. The British capacity market

The British capacity market is a centralised mechanism with descending-clock auctions held four years ahead of delivery, supplemented by year-ahead auctions for pre-qualified capacity [29,56]. While most capacity is procured four years ahead of the delivery year, the year-ahead auction allows last-minute adjustments according to updated forecasts. Companies that bid successfully enter a contract whereby they commit to provide electricity (or reduce consumption) when required in return for a monthly payment (premium). The premium (in £/MW-year) is defined as the auction clearing price based on marginal price (Fig. B.1). The demand curve is administratively defined by the Government with supporting analysis by the system operator, alongside an auction price cap, and a set of eligibility criteria [29]. Contracts vary in length based on the capacity type: one-year contract for existing assets, 3 for refurbishments and 15-years for new capacity.

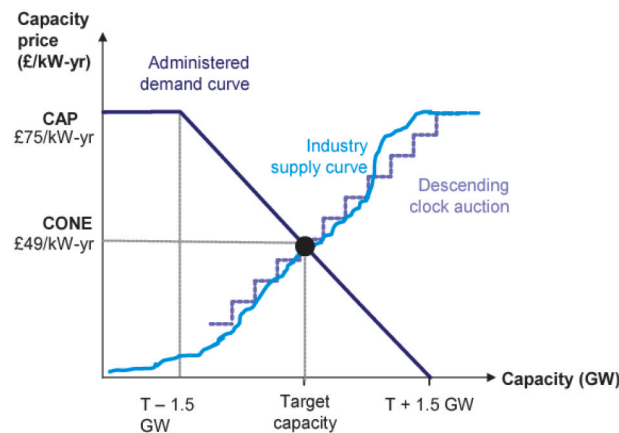


Fig. B.1. The British capacity market design [56].

B.2. The Italian capacity market

The Italian capacity market design is a centralised auction mechanism with Terna as the central buyer of reliability options [34]. Auctions are held yearly four years ahead of delivery, supplemented by three to a year-ahead auctions to allow for later adjustments. Auctions are held on a zonal level to coordinate capacity procurement and network investment planning. Plant owners who manage to secure contracts have an obligation to make their production capacity available in exchange for a fixed payment (in €/MW-year). The premium (in €/MW-year) is defined as the auction clearing price based on the marginal price. The elastic yearly demand curve defined by Terna on an annual basis, alongside price caps and eligibility criteria. The product traded in the Italian capacity market is a reliability option: this means that market participants must return to Terna the difference, if positive, between the wholesale energy and service markets' prices and the strike price pre-defined by the regulator ARERA. Contract length varies according to the capacity type with one-year contract for existing assets and 15-years for new built.

B.3. California's decentralised obligations mechanism

California's obligations scheme (Fig. A.2.3) relies on long-term contracts to encourage investment in new resources and shorter-term resource adequacy requirements to ensure that all capacity, including new and existing resources, are available to CAISO in the operational time frame [45,47]. The delivery of the obligations is placed on entities that act as electricity retailers, the so-called load-serving entities. First, load-serving entities must develop a non-binding 10-years procurement plan as part of the Integrated Resources Planning (IRP) process designed to ensure long-term resource adequacy [ibid]. Through the 'procurement track' of IRP, the CPUC can set obligations for the procurement of specific amounts and types of capacity within specific timeframes.

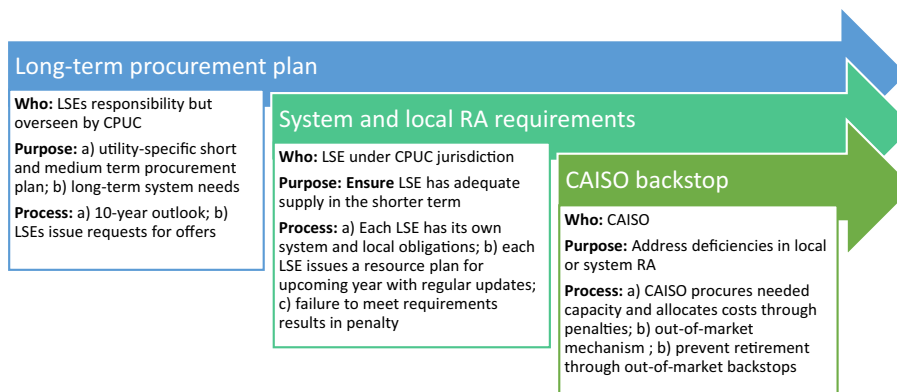


Fig. A.2.3. California's RA mechanism [45].

Second, load-serving entities must meet local and system requirements by procuring enough resources on a yearly and monthly basis to meet predetermined reserve margins [45,47]. Resources entering forward contracts with load-serving entities are required to bid into wholesale markets. The methodologies used by the CPUC for determining short-term reserve margins and the capacity values of different resources procured by the load-serving entities have evolved over time. The latest 'slice of day' requirements, to be implemented in 2025, involves separate capacity requirements for each month and hour of the day rather than the current requirements, which are pegged to monthly peak load [54]. CAISO also relies on an out-of-market mechanism to meet unsatisfied reliability needs, the so-called backstop mechanism.

References

- [1] M. Pollit, The future design of the electricity market, in: J. Glachant, P. Joskow, M. Pollitt (Eds.), *Handbook on Electricity Markets*, Edward Elgar Publishing, Northampton, 2021.
- [2] D. Newbery, M. Pollitt, R. Ritz, W. Strielkowski, Market design for a high-renewables European electricity system, *Renew. Sustain. Energy Rev.* 91 (2018) 695–707, <https://doi.org/10.1016/j.rser.2018.04.025>.
- [3] P. Joskow, Challenges for wholesale electricity markets with intermittent renewable generation at scale: the US experience, *Oxf. Rev. Econ. Policy* 35 (2) (2019) 291–331, <https://doi.org/10.1093/oxrep/grz001>.
- [4] R. Green, Shifting supply as well as demand: the new economics of electricity with high renewables, in: J. Glachant, P. Joskow, M. Pollitt (Eds.), *Handbook on Electricity Markets*, Edward Elgar Publishing, Northampton, 2021.
- [5] F. Wolak, Wholesale electricity market design, in: J. Glachant, P. Joskow, M. Pollitt (Eds.), *Handbook on Electricity Markets*, Edward Elgar Publishing, Northampton, 2021.
- [6] A. Bulbitz, D. Keles, F. Zimmermann, C. Fraunholz, W. Fichtner, A survey on electricity market design: insights from theory and real-world implementations of capacity remuneration mechanisms, *Energy Econ.* 80 (2019) 1059–1078, <https://doi.org/10.1016/j.eneco.2019.01.030>.
- [7] M. Hogan, Follow the missing money: ensuring reliability at least cost to consumers in the transition to a low-carbon power system, *Electr. J.* 30 (2017) 55–61, <https://doi.org/10.1016/j.tej.2016.12.006>.
- [8] M. Milligan, B.A. Frew, A. Bloom, E. Ela, A. Botterud, A. Townsend, T. Levin, Wholesale electricity market design with increasing levels of renewable generation: revenue sufficiency and long-term reliability, *Electr. J.* 29 (2016) 26–38, <https://doi.org/10.1016/j.tej.2016.02.005>.
- [9] T.O. Leautier, *Imperfect Markets and Imperfect Regulation: An Introduction to the Microeconomics and Political Economy of Power Markets*, MIT Press, Cambridge, 2018.
- [10] B. Clift, *Comparative Political Economy: States*, Palgrave Macmillan, Markets and Global Capitalism, 2014.
- [11] C. Kuzemko, C. Lockwood, C. Mitchell, Governing for sustainable energy system change: politics, contexts and contingency, *Energy Res. Soc. Sci.* 12 (2016), <https://doi.org/10.1016/j.erss.2015.12.022>.
- [12] A. Cherp, J. Vinichenko, J. Jewell, E. Brutschin, B. Sovacool, Integrating techno-economic, socio-technical and political perspectives on national energy transitions: a meta-theoretical framework, *Energy Res. Soc. Sci.* 37 (2018), <https://doi.org/10.1016/j.erss.2017.09.015>.
- [13] T. Jacobsson, A. Johnson, The diffusion of renewable energy technology: an analytical framework and key issues for research, *Energy Policy* 28 (9) (2000), [https://doi.org/10.1016/S0301-4215\(00\)00041-0](https://doi.org/10.1016/S0301-4215(00)00041-0).
- [14] F.W. Geels, Regime resistance against low-carbon transitions: introducing politics and power into the multi-level perspective, *Theory Cult. Soc.* 31 (2014) 21–40.
- [15] R. Karapin, *Political Opportunities for Climate Policy: California*, New York, and the Federal Government, Cambridge University Press, Cambridge, 2016.
- [16] Guerriero, C. (2016) The political economy of (de)regulation: evidence from the USA electricity industry.
- [17] A.F. Correlje, L.J. De Vries, Hybrid electricity markets: The problem of explaining different patterns of restructuring, in: *Competitive Electricity Markets: Design, Implementation, Performance*, F. Sioshansi. Elsevier, 2008.
- [18] E. Gawel, P. Lehmann, A. Purkus, P. Söderholm, S. Strunz, Political economy of safe-guarding security of supply with high shares of renewables, *Energforsk* 441 (2017).
- [19] D. Breslau, Designing a market-like entity: economics in the politics of market formation, *Soc. Stud. Sci.* 43 (6) (2013) 829–851. <http://www.jstor.org/stable/43284263>.
- [20] M. Lockwood, C. Mitchell, R. Hoggett, Unpacking 'regime resistance' in low-carbon transitions: the case of the British capacity market, *Energy Res. Soc. Sci.* 58 (2019), <https://doi.org/10.1016/j.erss.2019.101278>.
- [21] M. Lockwood, C. Mitchell, R. Hoggett, Incumbent lobbying as a barrier to forward-looking regulation: the case of demand-side response in the GB capacity market for electricity, *Energy Policy* 140 (2020), <https://doi.org/10.1016/j.enpol.2020.111426>.
- [22] S. Lenhart, N. Nelson-Marsh, E.J. Wilson, D. Solan, Electricity governance and the Western energy imbalance market in the United States, *Energy Res. Soc. Sci.* 19 (2016) 94–107.
- [23] F. Roques, D. Finon, Adapting electricity markets to decarbonisation and security of supply objectives: toward a hybrid regime? *Energy Policy* 105 (2017) <https://doi.org/10.1016/j.enpol.2017.02.035>.
- [24] M. Grubb, D. Newbery, *UK Electricity Market Reform and the Energy Transition: Emerging Lessons*, MIT-CEEPR, 2018.
- [25] E. Loeffler, T. Bovaird, *Public Administration Characteristics and Performance in EU28: United Kingdom*, European Commission, 2018.
- [26] Ofgem, Wholesale energy markets in 2015. https://www.ofgem.gov.uk/sites/default/files/docs/2015/09/wholesale_energy_markets_in_2015_final_0.pdf, 2015.
- [27] Ofgem, Electricity capacity assessment report 2013. https://www.ofgem.gov.uk/sites/default/files/docs/2013/06/electricity-capacity-assessment-report-2013_0.pdf, 2013.
- [28] Ofgem, Project discovery. https://www.ofgem.gov.uk/sites/default/files/docs/2010/02/project_discovery_febcondoc_final.pdf, 2010.
- [29] DECC, Implementing electricity market reform (EMR). https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/324176/Implementing_Electricity_Market_Reform.pdf, 2014.
- [30] National Grid, Final auction results — T-4 capacity market auction 2014. <https://www.emrdeliverybody.com/Capacity%20Markets%20Document%20Library/T-4%202014%20Final%20Auction%20Results%20Report.pdf>, 2015.
- [31] KPMG, Capacity market T-4 results. <https://assets.kpmg/content/dam/kpmg/uk/pdf/2021/03/kpmg-capacity-market-t-4-results.pdf>, 2021.
- [32] KPMG, The GB capacity market returns. <https://assets.kpmg/content/dam/kpmg/uk/pdf/2019/10/the-gb-capacity-market-returns.pdf>, 2019.
- [33] BEIS, Capacity market: 2021 consultation improvements. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/966729/capacity-market-2021-consultation-improvements.pdf, 2021.
- [34] MISE, Implementation plan. https://www.mise.gov.it/images/stories/documenti/Piano_di_implementazione_Reg_UE_943_2019-Mercato_elettrico.pdf, 2019.
- [35] ARERA, Relazione Annuale. https://www.arera.it/allegati/relaz_ann/15/RAVolumel_2015.pdf, 2015.
- [36] D. Cepiku, *Public Administration Characteristics and Performance in EU28: Italy*, European Commission, 2018.
- [37] P. Mastropietro, F. Fontini, P. Rodilla, C. Batlle, The Italian capacity remuneration mechanism: critical review and open questions, *Energy Policy* 123 (2018) 659–669, <https://doi.org/10.1016/j.enpol.2018.09.020>.

- [38] C. Kolokathis, M. Hogan, Market reform options for a reliable, cost-efficient and decarbonised Italian power system, in: *The Regulatory Assistance Project*, 2019.
- [39] MISE, Approvato da ARERA il decreto sul Capacity Market, June 28, 2019, https://www.mise.gov.it/index.php/it/198-notizie-stampa/2039889-approvato-da-arera-il-decreto-sul-capacity-market#page_top, 2019.
- [40] MISE, Piano Nazionale Integrato per l'Energia ed il Clima, Ministero dello Sviluppo Economico, Rome, 2019. https://www.mise.gov.it/images/stories/documenti/PNIEC_finale_17012020.pdf.
- [41] ANSA, Capacity market, Italia Solare e ambientalisti scrivono alla Ue, May 09, 2019, https://www.ansa.it/canale_ambiente/notizie/focus_energia/2019/05/09/capacity-market-italia-solare-e-ambientalisti-scrivono-alla-ue_b371a731-f63c-47ec-ae2d-7bd963b4d4ff.html, 2019.
- [42] SmartEn, State aid for resource adequacy: Recommendations for the revision of the Guidelines. Brussels. https://www.smarten.eu/wp-content/uploads/2019/05/smartEn-position-paper-Revision-State-Aid-Guidelines_FINAL.pdf, 2019.
- [43] Terna, Mercato della capacita' — Rendiconto degli esiti: Asta madre 2022. https://download.terna.it/terna/2019_12_06_Rendiconto%20EsitiAsta%202022_PUBBLICATO_8d7c06cc9f8470b.pdf, 2019.
- [44] Terna, Rendiconto esiti Asta madre 2024. https://download.terna.it/terna/Mercato_Capacita%20C3%A0_Rendiconto_esiti_Asta_madre_2024_8da140f8874afcd.pdf, 2022.
- [45] A. Sener, California—the coming retirement wave and the return of capacity pricing. ICF. <https://www.icf.com/insights/energy/insight-california-coming-retirement-return-of-capacity-pricing>, 2015.
- [46] CAISO, Final root cause analysis: mid-August 2020 extreme heat wave. <http://www.caiso.com/Documents/Final-Root-Cause-Analysis-Mid-August-2020-Extreme-Heat-Wave.pdf>, 2021.
- [47] NARUC, Resource adequacy primer for state regulators. <https://pubs.naruc.org/pub/752088A2-1866-DAAC-99FB-6EB5FEA73042>, 2021.
- [48] J. John, California's complicated path to changing its resource adequacy rules, GTM. <https://www.greentechmedia.com/squared/dispatches-from-the-grid-ed/ge/californias-complicated-path-to-changing-its-resource-adequacy-rules>, 2019.
- [49] CPUC, Proposed decision of ALJ Chiv and ALJ Allen, rulemaking 17-09-020. <http://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M266/K785/266785992.PDF>, 2019.
- [50] M. Jackson, Renewable electricity integration: a review of policy developments in Germany and their applicability to California, Berkeley School of Law. <https://www.law.berkeley.edu/wp-content/uploads/2018/11/Mathai-Jackson-Renewable-Electricity-Integration-A-Review-of-Policy-Developments-in-Germany-and-Their-Applicability-to-California-Final-July-2018.pdf>, 2018.
- [51] CAISO, Energy storage: perspectives from California and Europe. <https://www.caiso.com/Documents/EnergyStorage-PerspectivesFromCalifornia-Europe.pdf>, 2019.
- [52] G. Bade, FERC rejects generator proposal for CAISO capacity market, utility dive. <https://www.utilitydive.com/news/ferc-rejects-generator-proposal-for-caiso-capacity-market/542833/#:~:text=The%20Federal%20Energy%20Regulatory%20Commission,and%20mid%20Atlantic%20electricity%20markets>, 2018.
- [53] A. Mulkern, Calif. gives 'new life' to gas plants in emergency overhaul, E&E News. <https://www.eenews.net/articles/calif-gives-new-life-to-gas-plants-in-emergency-overhaul/>, 2022.
- [54] M. Specht, Changes to California's resource adequacy program will have huge consequences for the power grid, UCSUSA. <https://blog.ucsusa.org/mark-specht/changes-to-californias-resource-adequacy-program-will-have-huge-consequences-for-the-power-grid/>, 2022.
- [56] A. Barillas, R. Cohen, N. Sukthaworn, Lessons from the first capacity market auction in Great Britain, in: *12th International Conference on the European Energy Market (EEM)*, 2015.