Regulatory capacity and knowledge brokers in the decarbonisation of electricity systems

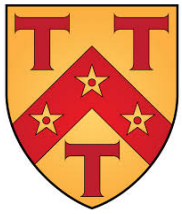
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Abstract

Many governments aim to rapidly expand the share of wind and solar energy in electricity generation as part of broader efforts to mitigate climate change. Despite being increasingly cost competitive, their integration into electricity systems requires adjusting a governance system intended for other technologies. This study contends that in order to better address technical and political challenges, regulators need to access scarce specialist knowledge. Regulators' access to such knowledge is dependent on brokerage, the strategic intermediation of actors in the industry, which can happen through different organisational arrangements. Power-generator and grid companies broker knowledge by providing expertise in ways that advance their own interests; whether that interest is to halt decarbonisation or capture the largest possible share of a growing renewable energy market. Independent system operators and expert organisations are alternatives for knowledge brokering that can be crucial to successful regulatory innovations. This research explores the mechanisms and significance of knowledge brokerage through the use of process tracing, network analysis and the controlled comparison of two liberalised electricity systems – Chile and the UK– and two state dominated systems –China and Mexico. Each pairwise comparison shows, independently, that knowledge brokers have become increasingly important in devising and deploying new market governance instruments that are relevant to renewable energy deployment. In liberal markets this is the result of a need to coordinate investment and create new market products. In state-dominated markets this is the result of a pursue to fragment and balance the influence of the state-owned grid and generation companies. The study shows that independent system operators and expert organisations can become substitutes, in terms of brokering specialised knowledge, but only as long as expert organisations are actively integrated in the regulatory process through delegation of crucial functions. This opens a discussion on developing regulatory capacity by developing and leveraging the competence beyond the market.

Keywords: regulatory capacity, renewable energy, knowledge broker, network analysis.

To Elena, with deep admiration.
And to all those, like her, that lead the way to make the world a fairer place.

In memory of Luis Robles Linares (1922-2021)

What is the central problem of social relations? It is the question of power; this is the problem of industry, of politics, of international affairs. But our task is not to learn where to place power; it is how to develop power.

Mary Parker Follett, 1924*

Table of Contents

Acknowledgements 3

1 Introduction 5
- 1.1 Research problem and objective 6
- 1.2 Argument 8
- 1.3 Research design and case selection 9
- 1.4 Findings and policy implications 10
- 1.5 Manuscript structure 14

2 Theory and research design 17
- 2.1 Success in decarbonisation as regulatory design 18
- 2.2 Theoretical framework 21
- 2.3 The knowledge broker hypothesis 27
  - 2.3.1 Knowledge exchange as mechanism 28
  - 2.3.2 Regulatory ecosystem analysis 31
  - 2.3.3 Hypothesis and research scope 35
- 2.4 Research design 37
  - 2.4.1 Process tracing and theory building 37
  - 2.4.2 Case selection and inferential leverage 40
  - 2.4.3 Interviews and network elicitation 43
- 2.5 Operationalisation of effective regulatory outcomes 44

3 Political goals, economic stakes and regulatory outcomes 49
- 3.1 Political goals and general trends 50
- 3.2 Regulatory outcomes in liberal systems 52
- 3.3 Regulatory outcomes in state dominated systems 57
- 3.4 Economic stakes in liberal systems 61
- 3.5 Economic stakes in state dominated systems 66
- 3.6 Outcomes, stakes and knowledge exchange 71

4 Knowledge brokers in liberal markets 73
- 4.1 The theoretical framework for regulatory governance in liberal regimes 75
- 4.2 Liberal regulatory ecosystems 78
  - 4.2.1 Chile 78
  - 4.2.2 UK 84
- 4.3 Enlisting or appropriating the system operator 89

4.4 Creating, enlisting and contracting domestic expert organisations 96
4.5 The absence of foreign expert organisations 102
4.6 Conclusions: regulators strive for redundancy 105

5 Knowledge brokers in state-owned industries 109
5.1 The theoretical framework for regulatory governance in state-dominated regimes 111
5.2 State-dominated regulatory ecosystems 114
5.2.1 China 115
5.2.2 Mexico 121
5.3 Enlisting or appropriating the system operator 127
5.4 Creating, enlisting and contracting domestic expert organisations 133
5.5 Engaging or nesting foreign expert organisations 142
5.6 Conclusions: regulators strive for rebalancing 151

6 Conclusions 154
6.1 Finding of emerging patterns of knowledge brokerage 156
6.2 Knowledge ecosystems without brokers 160
6.3 Policy implications 163
6.4 The future of electricity systems governance 166
6.5 Politics and knowledge brokerage beyond electricity 169

References 172

Appendix 1. Acronyms and names in local language 188
Appendix 2. Interviews 195
Appendix 3. Case selection 199
Appendix 4. Node-network description 202
Node statistics for Chile 204
Node statistics for the UK 205
Node statistics for China 207
Node statistics for Mexico 208
Appendix 6. Historical timeline of cases 210

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1 Introduction

The course of the decarbonisation of national economies is uncertain, even for those governments that have committed to net-zero emission. Political communities will make crucial decisions on what infrastructure is built, how it is operated, how it will be funded, and who will profit. And in contrast to a long history of industry-led decision making in both private liberalised and state-owned electricity industries, these decisions would be best made by public authorities. "On that kind of thing" said an executive from the energy infrastructure company National Grid "it's hard to see anyone other than government in the end taking a decision. So, the question is not really who takes the decision, it's who is advising them". Asset-owners, private or state-owned, have a seat at the table, allowing them to bring their knowledge –and interest– into the view of government regulators. But regulators can also approach or be approached by non-asset owners.

This research explores other agents that provide specialist knowledge to regulators –knowledge brokers– in remaking of electricity systems for decarbonisation. This research project was prompted by the observation of cross-country parallelisms in the changing governance of electricity systems. These include auctions and other central contracting mechanisms, the rebirth of public industrial planning, and the emergence of new markets products to facilitate the integration of solar and wind energy. Many of these innovations contrasted with the premise of the power sector liberalisation promoted worldwide since the 1990s by international institutions. A careful observation of the design and implementation of these instruments reveals the presence of actors that own no assets in the industry, including an independent system operator running auctions in Mexico, a university producing planning scenarios on the expansion of solar and wind

power in Chile, an engineering centre to monitoring curtailment in China, an experts committee setting decarbonisation targets in the UK. These actors are not the trade associations that are the source of knowledge in the classical liberal government, nor the autonomous expert agencies of the regulatory state, nor the state-owned industries of state capitalism.

The present chapter is divided into five brief sections to introduce the research problem, the argument, the research design, the main findings, and the structure of the manuscript. This full manuscript is divided into five chapters, including this introductions, and five appendices. One is dedicated to theory and research design. It is followed by three empirical chapters, one exploring the performance of electricity systems across in the four case studies, and two for the comparison of Chile/UK and China/Mexico respectively. The conclusion provides an analytical synthesis and policy recommendations.

1.1 Research problem and objective

A growing number of countries have adopted ambitious net-zero emissions targets that imply the need for full decarbonisation of electricity systems. In the United Kingdom, for example, the Future Energy Scenarios published by the National Grid Electricity System Operator concludes that to achieve the net-zero target adopted by the country "[t]he electricity system will need to operate using only zero-carbon generation and the power sector will need to deliver negative emissions (e.g. biomass with CCUS)". Earlier, less ambitious targets already required a large growth in the share of renewable energy. The European Union, China, India, Brazil, Mexico, the states of California in the United States, and the state of Kerala in India, are only a few examples of the hundreds of jurisdictions with an established mandate for the expansion of renewable energy (REN21, 2017a).

Fulfilling these government targets appears increasingly feasible due to the continuous reduction of costs from technologies like solar photovoltaic panels, wind turbines, or chemical battery

systems. However, recent research on investment trends signals serious challenges to scaling up renewable energy, and provides evidence of "power utilities lagging behind, and even hindering, the global transition to RE" (Alova, 2020, p. 924). Even if solar and wind energy are increasingly cost-competitive, their integration into electricity systems at growing scales presents serious regulatory challenges. Infrastructure and institutional legacy are not precisely favourable to deploying technologies whose energy resource shows significant variability across hours, days, and seasons. Regulators experience a time of high technological and institutional uncertainty and need continuous updates to the institutional framework that enables power systems to operate, from real time pricing of energy to long-term planning (Glachant, 2016; Rangoni & Zeitlin, 2020). For instance, regulators provide the rules around which generation plants interconnect, the rights and obligations inherent in becoming part of an integrated system, and the possible forms of compensation. Their decisions define the economic viability of renewable energy investment and determine who carries the costs and benefits of its deployment.

How are governments coping with the challenge of regulatory innovation? And why have some governments consistently managed their path towards renewable energy integration better than others? I argue that access to expertise and knowledge is key and can explain this variation, even between countries with similar levels of political ambition, regulatory capacity, or market liberalisation.

The policy literature remains focused on the role of liberalisation to explain performance in the industry, but the evidence shows level of liberalisation does not explain important features of performance in the industry, in particular regarding the integration of renewable energy. Policy scholarship needs to explore other institutional conditions that define the performance of the industry, for instance, what constitutes regulatory capacity and what resources do regulators have to govern the industry.

Regulators' access to knowledge depends on brokerage existing in different organisational arrangements. The industry itself brokers regulatory knowledge by strategically providing their expertise in ways that advance their interests. This is well understood in the political economy and regulation literature on electricity systems (Breetz, Mildenberger, & Stokes, 2018; Rangoni & Zeitlin, 2020; Stokes, 2020). Beyond the regulators and the power generation and grid companies, the involvement of actors whose main asset is expertise can be highly consequential. In this research, I show that both independent system operators (SO) and expert organisations (EO) in transnational networks are alternatives sources for knowledge brokering. I provide evidence that critical regulatory innovations for the deployment of renewable energy consistently rely on the participation of these knowledge brokers.

1.2 Argument

Governments rely on indirect governance as a matter of course. They allow specialised public agencies, private standard-setters or the industry itself to define rules and oversee compliance, due to a lack of competence or expertise (Abbott, Genschel, Snidal, & Zangl, 2019; Abbott, Levi-Faur, & Snidal, 2016). Autonomous agencies, private standard-setting bodies and consumer organisations all become intermediaries in the transfer of knowledge between the authority and the target of regulation. But an intermediary is not necessarily a broker.

A broker is characterised by its position connecting the regulator to knowledge that is specialised and hard to come by. Regulatory action depends on the industry's tacit knowledge –of the conditions of the local electricity system, as well the process of combining new electrical technologies into the local grid. And there might be few alternatives when it comes to accessing this knowledge. In the UK, the consumer organisation Citizens Advice is able to inform the regulator about utilities' quality of service but would be unable to identify the opportunities for doubling the interconnection capacity of offshore wind farms in Scotland. Apart from the regional

transmission company, who else would be a suitable position to provide the necessary regulatory knowledge?

I identify two means of increasing regulatory capacity: enlisting competence through delegating regulatory powers to expert organisations and establishing a direct relationship between the regulators and the system operators by increasing their independence from the electricity utility.

I postulate the following hypothesis:

> Greater access to system operators (SO) and expert organisations (EO) allows regulators to develop more innovative and effective regulatory solutions by increasing the provision of specialised knowledge, leading to an improvement in regulatory outcomes.

This project probes whether these two forms of brokering explain regulatory innovations and variance in the success of renewable energy integration success.

1.3 Research design and case selection

To probe the hypothesis, I developed a research strategy that combines within-case process tracing and a controlled case comparison. By combining the two inquiry methods this research benefits from the strong internal validity of the within-case analysis (Bennett, 2010; George & Bennett, 2005), and strong external validity of cases that are adequately matched (Slater & Ziblatt, 2013). Thus, the controlled case comparison enhances the possibilities of generalising from within-case process tracing.

The case selection increases inferential leverage by controlling for confounding variables. The literature overwhelmingly relies on the relative presence of market institutions as an explanatory variable for system performance. Therefore, I compare pairs of countries with relatively similar characteristics of liberalisation. Chile and the United Kingdom have fully private and liberalised markets, while Mexico and China have state-dominated and partially liberalised markets.

Furthermore, these cases are relatively close to each other in indicators of state capacity and climate ambition.

Given the diversity of structural and policy conditions that define regulatory outcomes, I utilise multiple indicators to assess the relative success in the integration of renewable energy, including quantitative and qualitative data points, including the share of wind and solar generation, the curtailment rates and business perception of curtailment risk, and the economic burden of grid constraints. I made an extensive review of secondary literature and administrative records according to the local context and availability between 2018 and 2019. I relied on statistic from public databases made available by the BP, the World Bank ESMAP Regulatory Indicators for Sustainable Energy, the Climatescope project of Bloomberg New Energy Finance and public funding agencies, as well as a domestic source of information.

I conducted seventy- one interviews across the four countries, which allowed me to build network diagrams for all of the cases. I was also able to identify the participation of intermediaries in multiple instances of regulatory innovations that were considered key to renewable energy integration. These instances referred to areas like wholesale market implementation, renewable energy auctions, and supervision of dispatching-rules compliance. The structure of the interviews allowed me to capture both network and process characteristics. I use social-network elicitation to characterise the regulatory ecosystem and identify plausible knowledge brokers and process tracing to specify the roles that knowledge brokers play in critical instances regulatory intervention.

1.4 Findings and policy implications

This thesis provides evidence that greater access to system operators (SO) and expert organisations (EO) enables regulators to develop more innovative and effective regulatory solutions by increasing the provision of specialised knowledge, improving regulatory outcomes. Moreover, it shows how crucial independent SOs are to the rapid deployment of new governance tools to

favour renewable energy, although there is also evidence that outright independence of the SO is not a necessary condition for success. Rather, the analysis shows that a robust network of EOs can serve as a relative substitute to moderate regulatory knowledge gaps.

Liberal markets can be characterised by regulators preference to build redundancy in the pathways to knowledge access. The UK shows this to be a structural feature with a large number of alternative EOs and mechanisms to fund and nurture their work as part of the regulatory framework. The great variety of asset-owners can partner with an equally varied array of EOs to compete for research funding. In addition, the UK government has not been cautious in creating new EOs like the Climate Change Commission and The Catapult centres. Chile shows a less rich ecosystem, but the domestic EOs contributed important regulatory knowledge at crucial political and regulatory junctures, as in the case of Energia 2050 policy debate. In the present, the creation of an independent SO has not yet undermined the pre-existing ecosystem of EO but created another path of intermediating knowledge.

In state-dominated markets the evolution of the ecosystem of knowledge brokers results from splitting incumbents, empowering domestic EOs and leveraging the knowledge of foreign EOs. These are all paths to ameliorate the potential negative consequences which would result from the dominance of state-owned enterprises. In opposition to the influence of grid companies, China delegated market implementation assistance at the provincial level to a selected number of universities and research institutes and empowered the research and design institutes through the creation of new centres with specific regulatory functions, like the China Renewable Energy Consumption Monitoring Centre. In Mexico, the unbundling of the SO represented a major shift in the distribution of knowledge as a resource, in addition to the other policy goals of unbundling like securing access to interconnection to new private developers. A common feature in the cases dominated by state-owned companies is that the rebalancing of power away from the state-owned

enterprises does not only happen through empowering private asset-owners, but through empowering other types of state-owned institutions.

The position of the SO is important enough that there are patterns across cases even with different levels of liberalisation. Chile and Mexico's redefinition of independent SOs as public agencies meant a re-concentration of authority and a new avenue for knowledge brokerage. The independent SO are hubs that concentrate the collaboration with domestic and foreign EOs. In contrast, the two countries with no independent SO, China and the UK, show a more diverse and robust ecosystem of EOs and even a growing split of functions between SO-like organisations. Without independent SOs, EOs collaborate directly with regulators or the private rule setters designated by the regulator. This is the case for market implementation initiatives in both China and the UK, where central regulators nurture or even demand EOs involvement in processes of system operation innovation.

A key finding from this research is that independent of SOs and EOs are substitutes. With no independent SO, the involvement of EOs is more consequential. This does not mean that regulators make a conscious choice between them. But rather that in the absence of an independent SO there is a vacuum where EOs have a latent opportunity for influence. Similarly, the presence of an independent SO reduces the knowledge asymmetry and, therefore, the potential role of EOs.

Finally, research findings also show when knowledge brokerage is not relevant. There are many instances of regulatory making where regulators obtain knowledge without a broker. In practice, this means that SOs and EOs do not close a structural hole because there are many alternative sources of the same knowledge. This is the result of three different interacting conditions: crucial tacit knowledge is codified and made explicit; this knowledge is widely diffused amongst many actors, and regulators limit the delegation of power to SOs or EOs. This finding is very important to understand why is it that knowledge brokers are particularly relevant at this historical moment,

when technological evolution means tacit knowledge is still crucial and there is still a limited number of actors with relevant knowledge about the interaction between renewable energy technologies and different local electricity systems.

The research project points to a number of policy recommendations. Public authorities have the capacity to create a favourable environment for regulation by utilising means of indirect governance. In fact, public authorities can shape the capabilities of EOs through delegating regulatory roles and contracting the production of key knowledge products. I derive three specific recommendations to improve the conditions for driving decarbonisation:

1. Build regulatory ecosystems (not merely agencies) and empower knowledge brokers.
2. Leverage and invest in the competence of intermediaries in governance reforms.
3. Embed international collaboration within appropriate local intermediaries.

Political authorities control over the industry is on the rise, even in state-dominated electricity systems, but not through classical forms of direct centralisation of authority in a ministerial-like organisation. Rather, the changes point to a concentration of decision making in political authorities embedded within richer networks of competent organisations that feed useful knowledge for their decisions. In this sense, delegating regulatory work to more competent organisations can reinforce the power the regulators.

With a turbulent future, shaped by high political pressure and rapid technological change, the future regulatory environment might benefit from more delegated power to those actors that are more accountable to public authorities, not only for the sake of improving implementation in the present, but to build stronger regulatory ecosystems for future challenges. Enabling, enlisting or creating knowledge brokers should be seen as a political means rather than a goal. The goal is ecosystem capacity, and knowledge brokers appear as transitory between a moment of rising knowledge gaps and a moment where many actors have command over the necessary knowledge to make better decisions. The success of any particular knowledge broker should result in its

demise as a powerful knowledge holder. These findings are relevant to other sector and countries were the knowledge gap between regulators and the industry can be wide and probably widening, for example, on finance and banking, as well as cyber security and digital services.

1.5 Manuscript structure

In addition to this brief introduction and a concluding discussion, this thesis contains one chapter to discuss the theoretical framework and research design and three empirical chapters. The "Theory and research design chapter" discusses the motivation and an argument for the use of theories of indirect governance, it also provides a conceptual representation of the electricity system as a regulatory system and present the core theoretical argument.

The first of the empirical chapters is dedicated to defining and measuring regulatory outcomes. No single statistic or index could adequately reflect the state of affairs across cases. Hence, this chapter presents a discussion of multiple dimensions to gauge the performance of the industry between 2015 and 2019, primarily, solar and wind energy growth rate, the economic significance of curtailment and the impact of interconnection limitations. It also explores the relations between these dimensions of performance and the challenges of political economy according to the structure of economic stakes in the industry.

The second and third empirical chapters correspond to the pair-wise comparative studies, first Chile and the UK as fully liberalised systems, and then China and Mexico as state-dominated electricity systems. These chapters explore the explanatory conditions and mechanisms in the knowledge broker hypothesis. Each chapter provides a discussion of the regulatory ecosystem for each case and presents the comparative analysis of the role of system operators, domestic expert organisations and foreign expert organisations. In these chapters I rely on the network elicitation and process tracing to produce evidence, the significance of which is best appreciated through a comparative narrative.

I use the concluding chapter to give a broader overview of the patterns of governance emerging from the empirical evidence and to wrap-up the findings about how and when knowledge brokers are relevant for regulatory action. The conclusions also present a brief discussion of the policy implications of these findings and the urgent need to re-emphasise regulatory capacity as a form of socially expansive institutional construction.

The thesis will name more than 100 institutions from the four cases. Hence, I combine the use of acronyms and full names throughout the text to ease reading. I include the names in the original language in footnotes when relevant for clarification.

I report all interviews under anonymity. All interviewees agreed to identify their institution, with the exception of one important interviewee in Mexico. Most interviewees agreed to direct references (quotes or paraphrasing) to their statements as long as their anonymity can be preserved. For consistency, I use few direct quotations, as I do not have recordings of the interviews regarding China. The decision to not recording interviews is China follows recommendations from other academics in the field.

To refer to interviews in the text, I use a code comprised of letters and numbers that differentiates between types of actors and cases. The first digit refers to the number of the case, *1* for Mexico, *2* for China, *3* for the United Kingdom, and *4* for Chile. A letter follows the digit to indicate the type of actors, *A*, *B* or *C,* for governmental, industry and other actors respectively. Finally, a sequence number identifies individual interviews; for example, 1A01 refers to the first interview conducted with a government official in Mexico. Appendix 2 provides further details on interviews conducted.

Appendix 1 provides further details on network diagrams, institutions, and the use of translations. Appendix 2 presents the list of interviews and a brief discussion on the fieldwork timeline. Appendix 3 contains an extended discussion on case selection. Appendix 4 provides a discussion

on network analysis results. Finally, Appendix 5 present the timelines of institutional reform of each case to accompany the empirical chapters.

2 Theory and research design

As stated by a business leader in Mexico, "the grid is the scarcest resource in the electricity industry" (1B05). System balancing and the expansion of the grid to serve future generators and consumers require the production of knowledge and tools that are appropriate to changing technical demands and institutional expectations. The industry must actualise algorithms, formal rules and informal practices in order to connect simultaneously a 40 years-old thermal power generation plant and a solar PV system with a Tesla battery. Across countries, the solutions might overcome the relatively similar technical problem of physical integration to grids, system balancing, and financial viability. However, in each different economy the solutions will respond to specific policy priorities, as well as a legacy configuration of rules and infrastructure.

The rapid transformation of electricity systems compounds two challenges for regulators, the problem of rent capture by public or private industrial organisations, and the limited capacity to respond to or advance technological change. These problems are interlinked because the institutional framework of the electricity service is adapted to different technological configurations (F. Geels, Sharpe, & Victor, 2019; F. W. Geels, 2010; D. Victor & Heller, 2008).[1] However, analytically we must distinguish between the problem of rent capture and the problem of regulatory competence in dealing with technological change. The distinction is important because technological change can increase the knowledge asymmetry between the asset-owner and

[1] For example, the wholesale market design schedules generation based on marginal generation costs. It is well suited for natural gas combine cycle power (NGCC) plants whose primary generation cost is the fuel, can easily express short-term marginal prices, and can transfer the risk of fuel price variability into the electricity markets. However, it might not well suited for technologies whose financing require long-term stable revenues (Borenstein, Severin; Bushnell, 2015). Nuclear, wind and solar energy generation technologies might face insurmountable risk to revenue sufficiency in a market running only on short-term trading.

the regulator, but in rapidly changing circumstances asset-owners can also find themselves in a position of limited knowledge of the technological frontier (Sabel, Herrigel, & Kristensen, 2017).

This chapter provides a framework to study the regulatory capacity in the context of technological change. The research hypothesis is based on the description of regulatory capacity as an attribute of the local institutional ecology. And I present this hypothesis as distinct and complementary to the theoretical developments that explain electricity systems performance based on the level of liberalisation focusing on subjects like state-private ownership and market segmentation.

In this chapter I first summarise the challenge of decarbonisation. Then I contrast the market design paradigm with the perspective of regulatory governance. I proceed to outline the research hypothesis and expectations. And finally, I discuss the research design.

2.1 Success in decarbonisation as regulatory design

Following the Paris Agreement commitment to hold the increase in the global average temperature to well below 2ºC and pursue to limit the temperature increase to 1.5ºC (UNFCCC, 2015, Art. 2), advanced economies will have to achieve near-full decarbonisation of their electricity systems at some point in the 2030s. Major developing economies will follow in the next two decades (IDDRI-SDSN, 2015; IPCC, 2018). But there is no clear technological, economic or political path to achieve this similar result in different economies. International institutions recognise this structural uncertainty and national variation, with parties to the Agreement are expected only to coordinate through ratcheting of autonomously established national goals –National Determined Contributions.

Decarbonisation is expected to occur through multiple paths of technological change. As a current sign of future developments, the International Energy Agency (2018) documents that solar and wind energy have experienced higher than expected growth rates, increasing their importance as leverages of decarbonisation in relation to other technologies that have not yet delivered tangible

benefits, such as like carbon capture from fossil fuel-based power plants. In this context, renewable energy targets have become an extended policy practice, with more than 200 national and subnational targets already reported to international organisations (IRENA, 2015; REN21, 2017b).

In the UK, the commitment to net-zero emissions will most likely require the full decarbonisation of the electricity system along with the expansion of electrification of heating and transportation services, as documented by the National Grid Energy System Operator (National Grid Electricity System Operator, 2019). But the trend is similar even for countries with more moderate trajectories of decarbonisation. For Mexico, Veysey et al. (2014) and Buira and Tovilla (2015), have concluded that there is a need for full decarbonisation of electricity generation in order to achieve the official target of limiting emission in 2050 to half of that observed in 2000. Available literature points to wind and solar PV as the most important generation technologies in these countries and other countries and others which do not have large built capacity of hydropower or nuclear energy.

However, solar and wind energy challenge the operation of electricity systems. These technologies are bounded by the availability of solar and wind resources, limiting the capacity of wind turbines and solar photovoltaic panels can make to meet instant demand. Moreover, in jurisdictions where electricity is traded by the marginal cost of energy generation, wind and solar energy can reduce the clearing price of the market when resources are more abundant, cutting-down their revenue base if they are compensated over wholesale market prices. Alternatively, as seen in a jurisdiction like China, authorities can curtail or dispatch down solar and wind energy wasting a large amount of zero marginal cost energy (Zhu, Qi, Belis, Lu, & Kerremans, 2019).

Decarbonisation of electricity system requires the fostering of particular pool of technologies through the regulatory framework on the operation, remuneration, and investment planning in the industry (Zinaman et al. 2015; IEA 2017; Wynn 2018; Newbery et al. 2017; Peng and Poudineh 2017; Helm 2017; Rhys 2016). Hence, governance in this transition period requires a continuous

revision of the institutional framework for the operation of the electricity industry as an integrated system around a grid (Glachant, 2016).

The centrality of regulatory action in electricity is not particular to decarbonisation. Modern electricity systems cannot be set apart from regulatory design. To argue that the state continuously reshapes all markets, Steven K. Vogel (2018) relies on the electricity sector for an indisputable example of *marketcraft*:

> The authorities have confronted daunting technical challenges in designing markets. They have to reconcile the operation of the power system, which requires centralisation, with competitive power markets that allow trading in electricity capacity. They have to create independent system operators so that neither the government nor the market players control the grid. They have to design a sophisticated auction system, combining auctions at different time points, such as day-before and hour-before. They have to adjust for the peculiarities of electricity markets, such as the limited number of bidders on the demand side and the relative inelasticity of supply. And they have to carefully balance the benefits of competition against the risk that generators and/or traders might exercise market power (2018, p. 35).

Success in decarbonisation through the expansion of renewable energy can come in many forms. In economies with renewable energy targets success is gauged by the expanding share of renewable energy in the short term, but also by cementing the political sustainability of further ambition in the longer term. Short-term success should not undermine the basis for increasing ambition. This means that authorities need to succeed in securing investment in renewable power plants, and simultaneously provide benefits to the economy or, at least, avoid imposing high economic costs to sectors with veto powers (Breetz et al., 2018; Stokes, 2020). But the political expectation of benefits and reasonable costs differs due to local political conditions and industrial legacies. The

benefits can come in the form of domestic value chain development or containing the economic burden to consumers.[2]

If success looks different in each case, failure is more uniform: infrastructure developers unwilling to invest, underachievement of national goals, and public backlash to existing pro-renewable energy policies. Higher energy cost and power outages could fuel the backlash from large industrial consumers, the general public or a particular electorate. However, absent a major failure event, the public, experts and policymakers use of noisy signals of performance which are not easily linked to specific policy choices. This is also a challenge to empirical research. The theoretical framework and research strategy address the problem of studying these complex outcomes.

2.2 Theoretical framework

The dominant academic perspective to study regulatory outcomes in the electricity industry has focused on the market design which established the structure of the sector and the economic incentives for firms operating in the industry. I argue that this approach misses the forest for the tree. In this section I discuss the complementarity between market design that focuses on the tree, and a regulatory governance perspective that sees the forest.

The market design literature serves as the foundation of contemporary debates for the governance of the electricity industry, through establishing the comparative superiority of wholesale market competition, privatisation, and deregulation (Breslau, 2011). An established view from industrial economics and political science is that liberalised energy systems are better at addressing problems of performance in the expansion of renewable energy. A liberalised system would provide the right incentive for the efficient operation of the industry through unbundling and privatisation, as well as competition and transparency through wholesale markets and an autonomous regulator

[2] Scholars emphasis value chain creation in countries like China or Germany (Nahm, 2017), but efficiency gains are also stresses as in the case of the cost-efficient innovations from long-term auctions despite not being an energy market mechanisms (Hochberg & Poudineh, 2018; Keay & Robinson, 2019).

(Besant-Jones, 2006; Foster & Rana, 2020; Urpelainen & Yang, 2019). These insights follow from studies of industrial economics that expect the market structure to predict the strategic behaviour of industry participants and, therefore, the performance of the industry (Joskow, 2008, 2014; Newbery, 2017; Wolak, 2014).

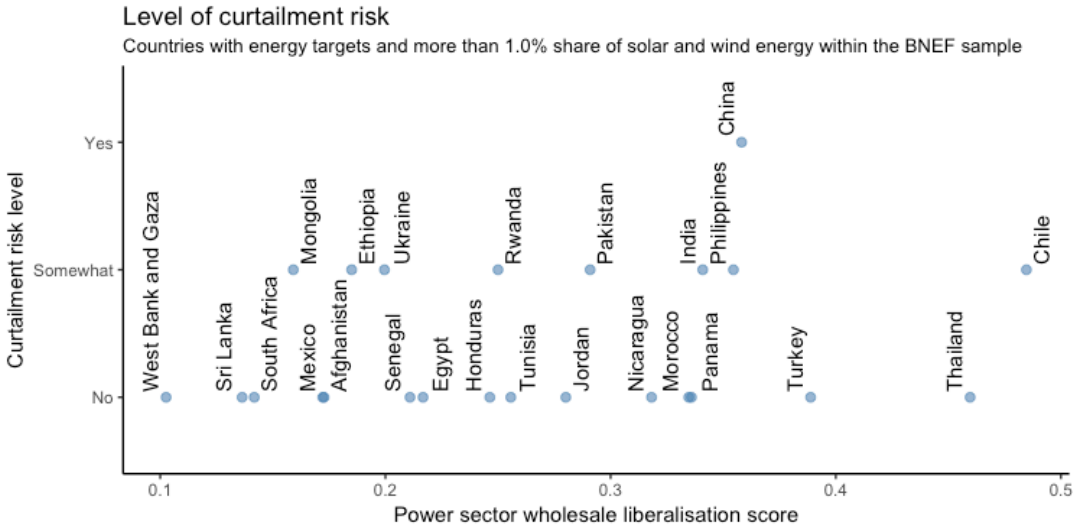
Political scientists also associates the structure of the industry with the opportunities to influence the processes of policy choice, adding additional arguments in favour of liberalisation (Gormley Jr. 1982; Berry 1984, Meckling 2018, Victor and Heller 2006, Aklin and Urpelainen 2018). Or alternatively focus on the lack of government lack of autonomy. Meckling and Nahm (2018), for example, argue that the divergence over the relative success of the implementation of climate policy in California and Germany derives from the relative autonomy and technical capacity of the public authority tasked with the rule making. Similarly, Isoaho, Goritz, and Schulz (2017) and Tsai (2014) for China; Baker (2017) for South Africa; and Bower and Fuentes (2014) for Mexico, identify low autonomy of central public authorities from the local state-owned power generation company as key factor in the limited transition away from fossil fuels.

Despite these advances in the literature, the evidence still shows that liberalisation does not conclusively result in improvements in the performance of electricity systems, in particular in the dimension of decarbonisations (Eun Kim, Yang, & Urpelainen, 2016; Pollitt, 2012; Shah et al., 2016; Streimikiene & Siksnelyte, 2016). In fact, in 2020 the World Bank's Energy Management Assistance Program (ESMAP) concluded that after thirty years of reforms, there is still inconclusive evidence that a coherent package of liberalisation is a necessary condition for a well-functioning electricity system. The ESMAP project *Rehinging Power System Reform* documented that good performance was present in countries with high adoption of liberalisation, as well as countries with low adoption of liberalisation (Foster & Rana, 2020).

Observations of the prevalence of curtailment risk experienced by renewable energy provide a similar account. The empirical evidence suggests that higher levels of market liberalisation do not

appear to entail lower levels of curtailment risk. Figure 2-1 illustrates the level of curtailment risk for the 24-case subsample as assessed by Bloomberg New Energy Finance (BNEF), in comparison with the score of wholesale market liberalisation index. The components of the index include the concentration of the power generation market, independence of power transmission companies, international interconnection, utility privatisation, utility unbundling, and wholesale power market. This figure suggests that the scores of important features of liberalisation are not sufficient to predict the presence or absence of curtailment risk in a market.

Figure 2-1 Level of curtailment risk and market liberalisation



Source: Author with data from BNEF (2018).

The idea that regulators are undermined by limited information from industrial operation is central to the market design literature. An asymmetry of information provides asset-owners with a resource to outmanoeuvre regulation or influence regulatory making. The institutions of liberalisation do not entirely solve the condition of information asymmetry but mitigate the negative consequences through the use of market competition to discipline individual industrial actors, and to increase the level of information available through price discovery in market exchanges. Scholars of market design recognise the relevance of non-economic institutions to moderate the negative consequences of information asymmetry while remaining outside of

parsimonious models of regulation. A wholesale market works better if expert organisations external to the market can access all market transaction information (Wolak 2014), and regulators of networks require accounting audits, benchmarking, and the opinion of engineering and management experts (Joskow 2014). The unstated assumption is that even the most sophisticated regulators in advanced economies rely on other actors to fulfil their supervisory role. Policy recommendations start to point to the forest, but the conceptual models rely only on the trees.

Beyond the electricity industry, scholars already describe the boundary of the regulatory ecosystem itself as political and intimately related to the nature of the knowledge required. Complex environments, as defined by McCarty, can be described as when "bureaucrats find it very difficult to establish autonomous sources of information and expertise about the consequences of different policies. In such cases, regulators are highly dependent on the regulated industry for both policy-relevant information and expertise […] or in professional schools and training programs in which the curriculum is favourable to industry interests" (McCarty, 2014, p. 102). In addition, the condition of uncertainty and rapid technological change undermines the capability of the authority to understand existing problems and foresee future problems (Sabel et al., 2017; Wegrich, 2019; Wegrich & Hammerschmid, 2017).

The participation of sources of expertise other than the regulated industry does not resolve the political problems, even external sources can be captured by special interests or can be simply left out by insulating the regulatory process from public or professional oversight (Culpepper, 2011; Kwak, 2014; Ramanna, 2015). It is nonetheless important to place these external sources of expertise and knowledge at the centre of the theories to explain regulatory outcomes, to describe the forest.

Government leaders rely on indirect governance, allowing specialised agencies, private standard-setters or the industry itself to define rules and oversee its compliance due to a lack of competence or expertise on the part of the governing actor. This entails that, like Abbott, Levi-Faur and Snidal

argue, "In many circumstances, regulators lack direct access to their targets, means of influence or other capabilities necessary to regulate them, and sufficient channels for information gathering" (2017, 18). According to their model of regulatory intermediaries, regulatory relations are better described as a chain of relations between regulators, intermediaries and target subjects (hence, the acronym RIT model). The intermediary is a go-between, whose presence necessarily makes some aspects of regulation indirect, as the intermediary stands between the regulator and its target" (Abbott, Levi-Faur, & Snidal, 2017, p. 19).

Introducing intermediaries could arguably improve the sector performance by closing the gaps of competences for governors. Competences are all the capabilities intermediaries can potentially contribute: expertise, credibility, legitimacy and operational capacity (Abbott et al., 2019). The specific consequences of participation of an intermediary in knowledge exchange and production depend on the type of relationship between the regulator and the intermediary. To describe these relations of indirect governance Abbott et al. (2019) describe two archetypes of intermediation formation: authority granting and enlisting. Granted authority can result in hierarchical delegation or non-hierarchical trusteeship, while enlisted authority can evolve into hierarchical co-optation or non-hierarchical orchestration. For example, Biermann and Rittberger (2020) use European regulatory networks to define regulatory triangles that allow regulators to increase control through the strategic addition of delegated intermediation on top of orchestration mechanisms, or the addition of orchestration on top of existing mechanisms of delegation.

Parallel paths of intermediations or regulatory triangles can be already described as networks of regulatory relations. In the classical work of Georg Simmel (1950) the triad is the most simple form of network. The theoretical and empirical tools of social-network analysis provide a framework to maintain theoretical parsimony when describing the complex distribution of competences relevant to the exercise of regulation.

The network approach allows researchers to identify specific organisations, functions and relations within the state and in relation to the industry. The imagery of networks has proven been a useful tool to portray the context-specific configuration of relations in which the structure (or topology) has an effect on the behaviour of an agent or the development of emergent phenomena, but which simultaneously at the same time results in more or less malleable patterns of relations (Padgett, 2011). Describing a regulatory relation as constituting a network can serve the double purpose of studying the aggregate regulatory capacity in the system, as well as the power dynamics, defined by concrete relations between the regulators, the target industry, and several intermediators. In 2004, Anne-Maire Slaughter (2004) argued for the relevance of understanding states and international institutions as disaggregated sets of organisations and individuals capable of establishing horizontal networks (across nation-state jurisdictions) and vertical networks (inward and outward with stakeholders).

In a context of scarcity of knowledge and uncertainty, intermediates can likewise be considered brokers. An actor is a broker when they connect other actors who would be otherwise unconnected. Brokers connect the technological frontier to the regulator. Their position provides them with power within resource-dependence relations. But their presence is relevant because it affects the dynamics of the entire system (Burt, 2001; Meyer, 2015; Padgett & Ansell, 1993). The identification of brokers denotes the potential moderation of asymmetry between the regulator and the asset owner, but also the source of agency and relational power for the brokers.[3] Thus, the perspective advances through network elicitation is to uncover a different map of political power in the regulation of the electricity industry.

[3] In a relevant example, Risse-Kappen (1994) provides evidence of the role of Berlin-based intellectuals bridging ideas between the otherwise disconnected policy circles in Moscow and Washington in the 1980s, giving them agency over the scope, content and direction of the future diplomatic conversations. The piece is suitable entitled: "Ideas do not Float Freely: Transnational Coalitions, Domestic Structures, and the End of the Cold War".

Political scientists and sociologists have already taken knowledge as a subject of the study of network exchanges for climate change policy adoption, as in the case of the diffusion of policy solutions like carbon cap and trading systems (Broadbent, 2017; Cao & Ward, 2017; Paterson, Hoffmann, Betsill, & Bernstein, 2014).[4] This scholarship shows that the study of social networks provides an advantage to complement the study of formal institutions by eliciting informal channels of communication. In similar arguments, several scholars have identified the layering of authority and the changing boundaries of regulatory environments in climate change. These studies have pointed to the relevance of private authorities and delegation of regulatory powers (Green, 2017, 2018), the existence of transnational sources of advocacy and ideas (Bulkeley et al., 2018; Hale & Roger, 2014; Kahler, 2017), the relevance of transgovernmental interactions (Paterson et al., 2014), and more traditional forms of international coordination such as international organisations (Florini & Sovacool, 2011).

In summary, this research intends to explore the implications of an understanding of regulatory action as embedded into larger networks of actors and institutions. This embedding defines the conditions of regulatory actions in ways that should be distinguishable from the implications of the market structure.

2.3 The knowledge broker hypothesis

This research attempts to answer how are governments coping with the challenge of regulatory innovation? And why have some governments consistently managed their path towards renewable energy integration better than others? I argue that access to expertise and knowledge is key and can explain this variation, even between countries with similar levels of political ambition, regulatory capacity, or market liberalisation.

[4] In contrast to the literature focusing on individual social networks, I study organisations as the location of knowledge and agency. In particular, I focus on the role of the state organisations as agents of networks' construction, such as the work over the developmental network state from Block (2008) or networked world from Slaughter (2004).

I hypothesise that greater access to system operators and transnational regulatory networks allows regulators to develop more innovative and effective regulatory solutions, by increasing the provision of specialised knowledge regarding the performance of the technologies, the behaviour of asset-owners domestically or abroad. As a result of the access provided by brokers, regulators are better able to proactively tackle emerging and foreseen challenges. In other words, for a given market design, access to broader sources of expertise (considering a wider set of actors) leads to outcomes of higher regulatory quality.

2.3.1 Knowledge exchange as mechanism

Knowledge is hard to come by for regulators. In the electricity industry, the ambitious goals of technological change affect the nature of the politics of energy, as it can create uncertainty and widen the gaps in knowledge across the industry, particularly for regulators. The challenge for regulators is to catch-up with the technological frontier, the most advanced technologies which could be deployed in the domestic electricity systems.

In the electrical island of Baja California Sur served mostly with expensive diesel and heavy fuel oil, the growth of renewable energy was abruptly paused due to grid operation concerns. The only alternative for development of new projects was the integration of large-scale storage. During fieldwork interviews in the spring of 2019, the Mexican regulator has had not yet published any specific regulation for storage technologies. A well-informed interview subject clarified that: "As in everything in Mexico, first the chicken then the egg. First, we develop the project, and then some day regulation will follow. If we wait the other way around, it won't happen. That's been the case" (1B05). The process was, nonetheless, coordinated with the SO with whom they engage regularly, almost daily, given that both the operators of the power plant and battery and the system operator must familiarise themselves with the new equipment and its effect on the entire regional grid.

This "chicken and egg" conundrum is, in fact, not unique to Mexico. The UK's National Grid Energy System Operator has a mandate to publish a frequent statement of potential standards and market product alternatives that could be utilised to reduce the cost of balancing services. The most recent instruments used to build this portfolio of alternatives is the Pathfinders program which provided the SO with significant discretionary powers to experiment with private's business propositions to test the business model and the physical operation of the service or product from the perspective of the control room (3B08). A new type of storage technology, a new business contract for providing frequency control, or a new mechanism to control demand at a local level, are all examples of these Pathfinding business and regulatory ideas.

During this early phase of deployment adoption is based on a combination of explicit and tacit knowledge in the hands of different actors. In the future, these experiences will result in regulatory decisions standardising the use of the technologies within specific businesses models that fit best within the regulatory framework.

Explicit knowledge is codified and can be easily disseminated and transferred, for example, in market transactions with consultants. Tacit knowledge is developed in experience and depends on a particular context. This distinction has been widely used to describe the challenges of value-chain creation in manufacturing. Tacit knowledge is a crucial component to explain successful enterprises of continuous innovation (Berger, 2013; Herrigel, 2010; Nahm & Steinfeld, 2014), as well as regulatory innovation (Sabel et al., 2017). More generally, there is an established tradition in political analysis that recognises economic systems as being based on context-specific knowledge, associated with specific problems, technological configurations, and labour and management skills (Follett, 1924; Ansell, 2011; Piore & Sabel, 1984).

In the electricity industry, there are at least two areas of tacit knowledge. On the one hand, there is a tacit knowledge about of the local electricity system, due to the specific industrial legacy that differentiates electricity systems across jurisdictions. This is relevant despite the high level of

standardisation in equipment across the industry. On the other hand, there is tacit knowledge about the operation of technologies like wind turbines, PV panel systems, chemical batteries, and their combination at different scales.

The 'tacit' character is context and history-dependent, as there is always the possibility for specific forms of knowledge to become more widely available, encoded and explicit. And these two subsets might not be in the hands of the same actors. A foreign firm might have significant tacit knowledge of offshore wind turbines deployed in the North Sea but have limited knowledge of the local grid system adjacent to the China East Sea. The local grid company is in the reverse position. In phases of transition, translating between contexts and utilising tacit knowledge requires specific forms of industrial competence based on learning by doing in the industry and the actors with appropriate skills and existing pools of knowledge for the exercise of extrapolation.

Michael Davidson argues that shortening the period of scheduling and improving forecasting of wind and solar energy can reduce the amount of wind curtailment in China (Davidson, 2018).[5] These two measures are widely discussed in the literature as 'low-hanging fruits' for improving renewable energy integration and reducing the costs created by their variability (IEA, 2019). However, forecasting wind and solar energy are not traditional tasks in energy systems and particularly for regulators or system operators, which have relied on generators knowledge of their own operational conditions. In Chile as in Mexico, system operators relied on EO organisations to acquire the tools, software and training to be able to utilise forecasting services for their operational planning and dispatching decisions.

Establishing the link between a regulatory tool and a form of tacit knowledge is challenging. A cost benefit analysis is a very common example of a regulatory tool. I focus on electricity industry specific tools, software as used for dispatch scheduling, products like grid expansion models and

[5] Under the current criteria, generators individually develop their own forecast and provide it to dispatching centres (2B01).

scenarios, or wind and solar forecasting systems. These tools and products are not the only forms of knowledge, but they leave traces of transfer within the regulatory ecosystems and can testify for successful knowledge exchange, because they require at least one of the two types of tacit knowledge and commonly both the local system and the technology.

2.3.2 Regulatory ecosystem analysis

I follow the regulatory intermediaries' literature applying it to the electricity sector to establish four categories of actors. Regulators encompass political authorities (also called governors) and economic or technical regulatory agencies. The target industry includes asset owners in the businesses of generation, transport and ancillary services provision, and their technology providers. System operators (SO) refer to dispatching centres, power exchanges, trading and settlement agencies. Finally, expert organisations (EO) include universities, research centres, specialised policy and technical cooperation programs that engage in the production and reproduction of knowledge about the technical frontier. SOs and EOs are not asset owning actors and, therefore, their interest is not defined by a rate of return on investment.

System operators can provide specialised knowledge about the behaviour of the target industry based on expertise derived from their own operational and supervisory roles. System operation is a collection of functions that are necessary for electricity systems; therefore, even under integrated utilities, there is an office that performs the role of the system operator. South Africa's Eskom, an integrated utility, performs the role of system operation. In the UK, the role is held by the transmission company National Grid. In Mexico, the legal creation of an independent system operator entailed the subtraction of the National Energy Control Centre from the state utility, to become a legally independent body under the direct jurisdiction of the Ministry of Energy. Hence, the level of access to system operators that regulators enjoy depends on the level of independence from the generation and transmission companies.

In the UK, the expectation is that SO would facilitate competitive markets, supporting competition in network, act as residual balances and facilitate whole system view (BEIS, Ofgem, & Grid, 2017, p. 8). This enumeration of regulatory expectations speaks to the critical role of SOs. An expert with a long career in system operation in Chile observed that "Whatever the model, for a long time already, the electricity system operator is the knowledge centre, the analytical arm, the muscle of the authority […] The authority always looked for the support of the operator because they knew the risks, they administrate the risk, they had projections that were better. Therefore, it is the input for decision making of authority" (4A03).

Why is independence relevant? A senior official from the Chilean SO clarified that the transition from being under the control of the asset-owners to an independent government agency has a very practical meaning: "More eyes, but fewer vetoes". To this official this meant less obstruction from the grid and generation companies that governed the institution to respond to new regulatory or technological requirements. At the same time, it meant more public scrutiny as a stand-alone agency accountable to public regulators, parliamentary inquiries and the broader public. It is important to consider that the under industry control, the SO is therefore subjected to the preferences of the incumbent industrial actors, and not incoming firms with different technological solutions.

The creation of the independent public SO in Chile cannot be distinguished from the policy decision to physically integrate what had been two independent interconnected systems in the country, which was finally completed in 2017. The purpose was not only two unify two dispatching organisations, but to unite within a single actor a number of new functions required by the latest market reform, including on expanding the role of central grid planning and supervision of the grid infrastructure, as well as placing the authority over the technical review for interconnection in the hands of a public agency. All of these functions were either non-existent before or had been in the hands of the few transmission network operators. The creation of the Coordinador,

therefore, represented an important upset to the capability of private operators to influence the future development of the industry.

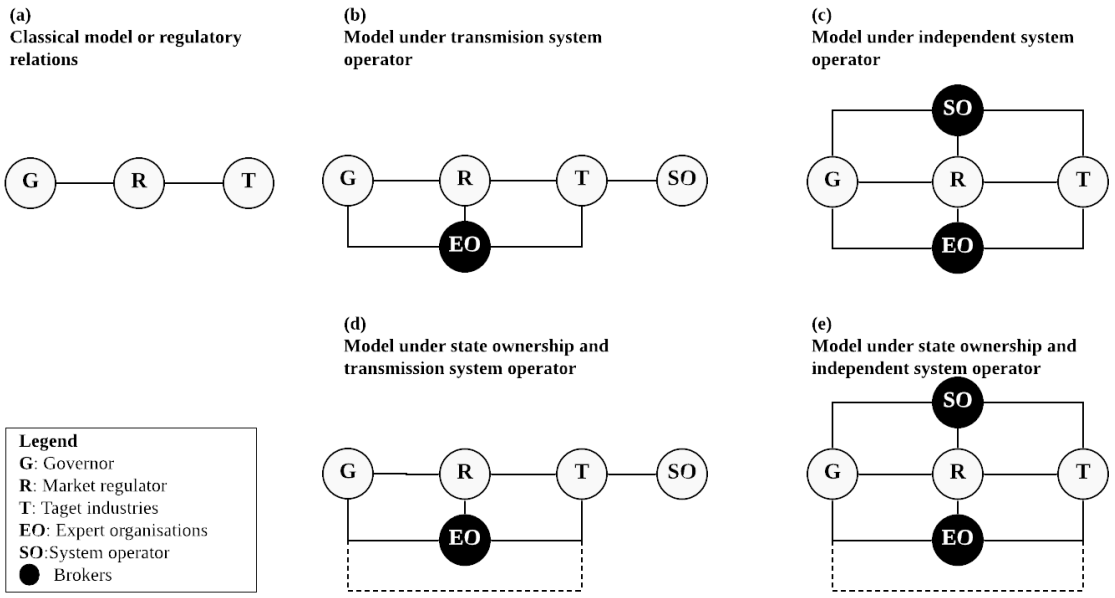
In the UK, the separation of the SO from the National Grid also followed discussions about infrastructure development. Under the existing conditions, the regulators reviewed proposals from private developers to expand the network based on their own assessment and the development of a ten-year plan. One concern was, for example, that the overinvestment in interconnectors with continental Europe, instead of exploring local and more economical sources of balancing or the lack of further investment to increase interconnection with wind-rich Scotland. Ultimately, the regulator recognised the need for a comprehensive perspective for the development of the system, beyond increasing interconnection to Europe. This represented a pushback against the growing interconnector business of the National Grid.

This "fewer vetoes" putatively applies to all types of actions, for example, on implementing new dispatching algorithms or revising the rules of interconnection, but also, for sharing knowledge and working with the regulators. And regulators recognise the importance of system operators. Regulators refer to system operators as central in the reshaping of electricity markets. For instance, in Chile, the regulation of the ISO establishes the obligation to preserve the security of the electricity service, ensuring the most economic operation for all the electricity systems, and guaranteeing open access to all elements of the transmission infrastructure (Decreto 52, 2018). System operators are the backbone of the regulatory system.

As an organisation that is not defined by an asset, but rather by the provision of a highly technical service, I see a SO as a type of expert organisation in itself. But there are many more types of expert organisations that could potentially provide highly valuable knowledge to regulators. Engineering research centres and consultancies. As I discuss in the corresponding chapter, Mexico considered hiring a multinational company to implement wholesale market operating systems instead of the SO and local EOs implementing the process.

Figure 2-2 describes five models of regulatory architecture. Model (a) represents the classical perspective of regulatory relations, in which a political governor delegates authority to a specialised market regulator to govern over the target industry. Models (b) to (e) represents variants of the models studied in this research, recognising the role of system operators and expert organisations as parts of regulatory relations given two types of structural conditions. These structural conditions are the position of the system operator and the existence of state-ownership. Model (b) corresponds more closely to the United Kingdom, model (c) to Chile, model (d) to China, and model (e) to Mexico.

Figure 2-2 Models of indirect governance in the electricity industry



Source: Author.

All of the complex models (b to e) include expert organisations. This is an informed expectation but will have to be documented during the cases studies, therefore it is not used to characterise types of regulatory relations or to select cases. Expert organisations are research centres or specialised advocacy organisations, inter-governmental networks of practice, and regulatory learning networks which might provide information and insights that are relevant for domestic

regulatory making, including through the existence of transnational networks of knowledge exchange (Haas, 1989; Roger, Hale, & Andonova, 2017; Slaughter, 2004).

The case studies show a great diversity in the articulation of the SO and EOs, but the typology facilitates organising a comparative study to investigate empirical hypothesis.

2.3.3 Hypothesis and research scope

Following the characterisation of actors, I postulate the following hypothesis:

> Greater access to system operators and expert organisations enables regulators to develop more innovative and effective regulatory solutions by increasing the provision of specialised knowledge, leading to improved regulatory outcomes.

The effective regulatory solution can be documented by actual regulatory changes specifically targeted to solve problems of renewable energy integration and should be evaluated based on the contribution to sustained growth in the share of variable renewable energy, maintaining (or reducing) the levels of curtailment, and facilitating interconnection –the signals of performance introduced earlier.

This hypothesis will probe the more general argument about the causal significance of knowledge production and exchange beyond the industry ('knowledge brokers hypothesis'). This explanation is complementary to the arguments that explain performance as a consequence of relative liberalisation ('liberalisation hypothesis'). The research challenge is, therefore, to provide evidence that knowledge matters, independently from the effect of the institutions of liberalisations. The liberalisation hypothesis has been inconclusive, but this research does not attempt to falsify it. Rather, this research builds a coherent body of evidence for the relevance of knowledge exchange relations in explaining regulatory capacity and success. Studying how the knowledge brokers hypothesis works under different market designs shows how features like the independence of SO

and the presence of EO can be orthogonal to liberalisation institutions, and therefore contribute to explain, in its own right, policy success.

Under the research design, I established two types of observable implications from the hypothesis. First, I expected to observe positive performance in the presence of independent domestic intermediaries and transnational regulatory networks and lower levels of curtailment. These are summarised in Table *2-1*.

Table 2-1. Observable implications: the joint presence of conditions[6]

Joint-presence observations
a. Regulator's higher access to expert organisations is associated with sustained growth of wind and solar energy and low curtailment and interconnection limitations.
b. Regulator's higher access to independent system operators is associated with sustained growth of wind and solar energy and low curtailment and interconnection limitations.

I also expected to observe evidence of regulatory change involving intermediaries in three areas of regulatory action. Firstly, I focused on the implementation of reforms to the mechanisms of operation and exchange, for example, the implementation of wholesale markets. Secondly, I focused on the mechanisms of contracting by central authorities, for example, auction systems. And finally, I focused on the problem of planning. Increasingly, governments are expected to coordinate the contracting of renewable energy in order to secure revenues for developers independently of the variability of markets.

The process-oriented observations described in *Table 2-2* allow me to establish the presence of brokers and qualify their participation within cases. The strength of the findings depends on the consistency of evidence of the brokers role in catalysing regulatory innovations.

[6] I do not use the term correlation because these observations will be based only on two historical cases and not a large number of discrete observations.

Table 2-2. Observable implications: process-oriented observations

Process-oriented observations
a. System operators and expert organisations participate in the implementation of market reforms.
b. System operators and expert organisations participate in the implementation of central contracting mechanisms for renewable energy.
c. System operators and expert organisations participate in the implementation of new forms of planning.

2.4 Research design

To present the research design, firstly, I discuss the combination of process tracing and comparative analysis as inference strategies for theory building. I discuss the operationalisation of the mechanism of knowledge exchange and discuss the use of case selection to gain inferential leverage. I continue by explaining the use of network elicitation through interviews as an empirical inquiry strategy in the fieldwork. Finally, I discuss the operationalisation of regulatory outcomes.

2.4.1 Process tracing and theory building

As described by Andrew Bennet "Process tracing involves the examination of 'diagnostic' pieces of evidence within a case that contribute to supporting or overturning alternative explanatory hypotheses" (2010, p. 208). This research strategy relies on the instantiating, with empirical evidence, of a theorised mechanism of action. The researcher establishes a hypothesis with observable implications against which empirical evidence is evaluated.

The search for evidence is guided by the theory-informed implications. It must be suited to facilitate discriminating evidence based on its potential contribution to supporting or overturning a hypothesis. Having a number of pieces of evidence, the researcher evaluates the congruence

between the theoretical expectations and the pool of evidence at hand. In this research, the models of indirect governance in the electricity industry presented above serve as the theoretical basis to specify the expectations from cases, based on the two dimensions where there is variation: state-ownership and independence of system operator. Each comparative chapter will therefore discuss the specific theoretical expectation for the particular pair of cases.

The evidence also encompasses the absence of a piece of information, record, actor or event, since the lack of administrative record or scarce appearance of a subject in an interviews might be indicative of relevant phenomena (Gonzalez-Ocantos & Laporte, 2019). This is particularly relevant to this research, as I draw inferences from administrative records and interviews about actors' interactions. I expected certain actors to appear prominently in interviews, if they did not, it is also meaningful to the research. This was the case of multilateral banks, whose presence I expected in Mexico, China and even Chile. Fieldwork interviews proved me wrong. Their absence in interviewees' response denoted that these financial institutions do not sit at the technological frontier and they are not relevant to regulators in these industrialised economies. Similarly, the lack of a formal curtailment statistic in Mexico is a very strong signal of the limited impact it has on businesses.

I choose specific regulatory events where it is possible to instantiate the existence of a mechanism and the presence of actors. The strength of the findings of this research depends on evaluating whether the presence of brokers does indeed catalyse regulatory innovations by looking into these areas of regulation making. I considered the possible causal paths where brokers, even if present, are irrelevant (lack of *causal depth*, as discussed by George and Bennett 2005). To evaluate the causal depth of the evidence I will rely on two strategies, firstly, to establish instances of the causal mechanism, and secondly, to evaluate the congruence between different pieces of evidence.

I gather substantial information and evidence from each case in order to establish the sequence of events in regulatory processes and the specific structures of relations between regulators, targets,

and intermediaries –both foreign and domestic. I followed two strategies for evidence collection. The first strategy is to gather evidence from secondary sources on institutional and industrial organisation, and primary documentation of policy-making processes such as regulatory records. The second strategy is to conduct semi-structured interviews with officials from public and private organisations that participate in the regulatory process.

I evaluate the congruence between observations in records and interviews. Regulatory records allow me to draw observations regarding the participation of brokers: records of meetings, policy-memos, technical reports and other traces of engagement. However, interviews allowed me to develop a more comprehensive perspective of brokers' presence and of their relative importance in contributing to rulemaking and implementation, and to discriminate from abundant primary sources, such as like opinions provided in public consultation.

One of the key tasks was to establish whether particular actors had an interest in favour or against the expansion of renewable energy. In a rapidly changing technological and political context, interests are malleable (Breetz et al., 2018), or the salience of a particular regulatory tool might be low or undetermined (Culpepper, 2011; Stokes, 2020). This was particularly observable in the instrumentation of planning tools; whose impact is less evident as they might intend to be exploratory and expand the knowledge for further discussion. Hence, stakes are low given other more immediate priorities, for example, on tariff setting. Other regulatory tools, like those of compensation over curtailment, entail larger and more evident stakes but even in these cases companies can transition to different business models in order to mitigate potential costs. The empirical chapters make use of secondary research and interviews to clarify the stakes and interests of incumbents regarding the regulatory innovations discussed in each case.

The controlled case comparison enhances the possibility of generalisation based on within-case process tracing. By combining the two inquiry methods this research benefits from the strong internal validity of within case analysis, and strong external validity if cases are adequately matched

(Slater & Ziblatt, 2013). Therefore, case selection is fundamental to the possibility of partial generalisations.

2.4.2 Case selection and inferential leverage

The purpose of case selection in a comparative study is to leverage similarities and differences to infer causal relevance of specific conditions of interest (Seawright & Gerring, 2008). In addition, as argued by Slater and Ziblatt (2013) the close matching of cases can allow the research to pursue a certain level of generalisability. This is achieved not through selecting a representative sample of the population, but rather by selecting exemplary cases that are theoretically meaningful. Furthermore, given the historically contingency of institutional evolution, controlled comparison informs the latent institutional functions, for example, a regulator that conducts no long-term planning, but which we know could happen given the observation of another similar case.

In this research, a case is a regulatory cycle, which starts after a policy shock and is geographically bound within a regulatory jurisdiction. Regulatory cycles are formed by multiple regulatory events which are part of a program with relative coherence. These cycles last years and might be associated with large changes in government coalitions, policy commitments and technological and economic disruptions. For simplicity, I describe cases by the name of the jurisdiction, but it would be possible to describe distinct regulatory cycles in a particular jurisdiction.

I focused on regulatory events that followed the signing of the Paris Agreement in 2015, which raised climate ambition across countries and coincided with solar and on-shore wind energy reaching the bottom of the experience-cost curve. The length of the episode is specific for each jurisdiction. However, between 2014 and 2015 the four cases initiated large processes of reform, launched by legislation in the case of Chile, Mexico and the United Kingdom, or a robust political mandate in the case of China. In Mexico, the cycle ended in December 2018 with a new

government that explicitly proposed to halt many of the policies pursued by the previous administration.

I attempt to gain leverage to explain the role of brokers under different levels of market liberalisation through case selection. I offered evidence that the level of liberalisation does not provide a sufficient explanation to explain curtailment, though I still expect it to be a significant condition. Therefore, I utilise liberalisation and the independence of the system operator as criteria for matching cases to explore the effect of the independent variable. This research strategy combines the use of diverse cases over the presence of brokers and the matching cases according to the alternative hypothesis of market liberalisation.

Table *2-3* presents the two-dimensional matrix used to match cases according to the criteria. I selected four countries, Chile, China, Mexico and the United Kingdom. These four countries were selected from the review of cases of potential international relevance, understood as membership to the Clean Energy Ministerial mechanism. These cases have depended on thermal power generation, in contrast to others like France that is heavily dependent on nuclear, or Brazil that relies on hydropower. Appendix 3 provides an extended discussion on case selection and alternatives.

Table 2-3. Case selection

	Liberalised market	Partially liberalised market
Independent System Operator	*Chile*	*Mexico*
No Independent System Operator	*UK*	*China*

The most relevant variable that characterises partial liberalisation in both China and Mexico is the existence of state-owned enterprises. Therefore, this comparison provides crucial evidence to argue that the presence of brokers is an omitted variable in market design studies and allows me

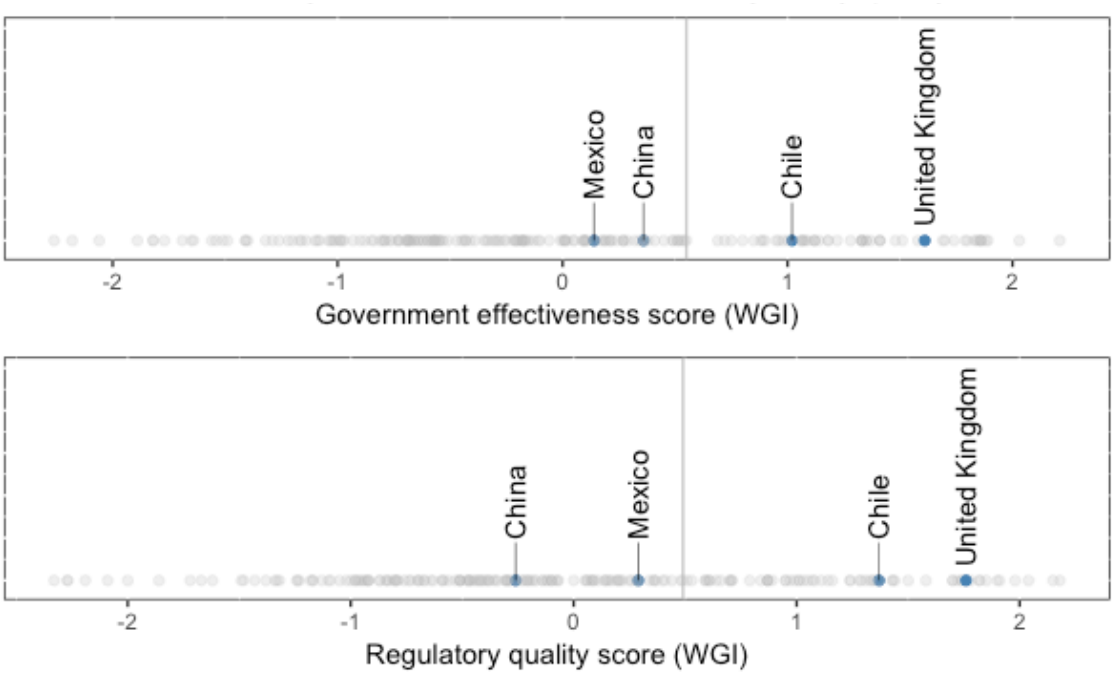
to document the mechanisms of exchange that take place with and without the presence of specific types of brokers in state-dominated systems.

Within fully liberalised markets, curtailment has been less severe, or regulators have been able to curve it with relative success in most cases. Both cases instrumented reforms to the position of the system operator, Chile in 2015 and the UK in 2017. However, Chile fully unbundled the system operator, while the UK only provided some autonomy from the grid company without full unbundling. This contrast will allow me to capture the variations between the different depth of independence.

Existing comparative literature on energy policy usually distinguishes between developed and developing countries. This research de-emphasises income differences and focuses on institutional context. There is a large gap between the GDP per capita of the UK on the one hand, and China, Mexico and Chile on the other. However, average income level was relevant to explain the past trends in the uptake of renewable energy through the use of subsidies, but less so as renewable energy costs diminish. It is more appropriate to account for measurements of government capacity and regulatory quality at a national level.

Figure *2-3* present two indicators of the comparability of the paired cases. The Worldwide Governance Index 2017 (Kaufmann and Kraay 2018) reports scores on government effectiveness and regulatory quality. A dividing line has been drawn according to Andrews, Pritchett, and Woolcock's (2017) criteria to distinguish the high government effectiveness group (at the score value of Uruguay). Chile and the UK are significantly closer to the upper boundary of the score, while China and Mexico are still relegated to the middle of the range, confirming the suitability of this case comparison.

Figure 2-3 Scores on government effectiveness and regulatory quality



Source: Author based on Worldwide Governance Index 2017.

2.4.3 Interviews and network elicitation

Armando Razo (2017) argues that network analysis can be used in comparative politics for operationalising social structure, the modelling of informal structures, and the analysis of relational data. Hence, researchers can integrate social structures of communication and deliberation that map on to existing frameworks for regulatory decision making. Additionally, the descriptions of communication channels can be utilised to identify brokers in the regulatory system. This can be done analytically through visual representations or through descriptive network statistics. In the comparative chapter I rely on both the visual representation and network statistics.

I have made the following relevant research choices in response to key methodological and practical concerns identified in the literature of social network analysis (Marsden, 2011; Wasserman & Faust, 1997). Interviews provided information for network depiction, but they also provided detailed information about sequences of events, information exchanges and nuances from their

own interpretation of the processes. I specified both the existence of the relationship and the type of content through name generator questions and resource generator questions. I used name generator questions to elicit the relations between concerned organisations (ego) and other organisations (alters). I utilised free recall questions, complemented with additional probing. Resource generator questions are used to elicit the content of exchanges. I posed questions regarding the access to certain types of resources (software, technical opinions, modelling studies). In total, I conducted 74 interviews with more than 90 people (some meeting included more than one person), with the least in China and Chile (N=15) and the most in Mexico (N=26). These represented more interviews than the original target of 10 interviews per case.

The selection of the interviewees was informed by the theoretical proposal and the documental review. The sources to inform case selection varied widely amongst the cases. I avoided snow-ball sampling. Only in China did I reach out to two actors that were not originally identified in the documental review as I learned more about the case in the field. In particular, this was the case of the China Electricity Council, one of the oldest institutions in the industry which I assumed to be a government statistical agency. As an example, in the UK, Ofgem consultations over the separation of the System Operator from the National Grid in 2017 provided a rich basis for sampling. In China, the selection was made based on published work of the China National Renewable Energy Centre and tracing the original policy documents discussed in specialised working groups on system modelling under the Clean Energy Ministerial. In Mexico and Chile secondary literature and professional knowledge of the cases facilitated the selection process.

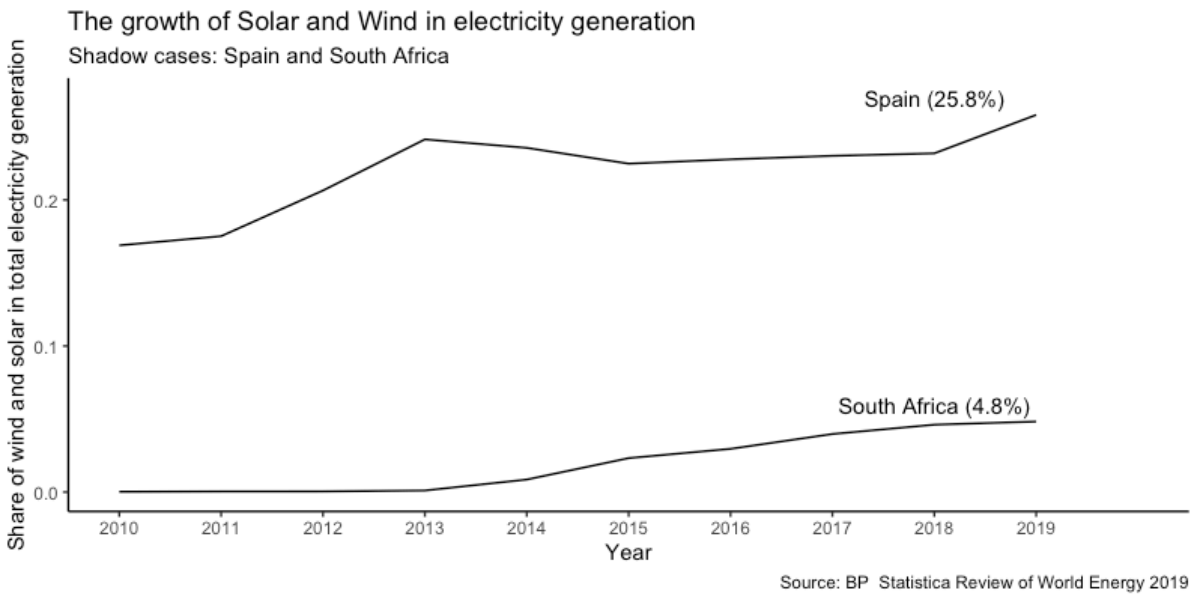
2.5 Operationalisation of effective regulatory outcomes

From a decarbonisation perspective, the desired outcome is a rapid and sustained growth in the share of low-carbon energy sources for electricity generation. Governments committed to deliver on this agenda deploy multiple regulatory and investment tools. A direct subsidy as a feed-in-tariff that guarantees a certain revenue stream to generators might be successful as investors take on the

opportunity offered by the government. However, the case of Spain shows that a very large fiscal burden can result in a major backlash that halted the growth of wind and solar energy for half a decade starting in 2012. Figure 2-4 shows this hiatus for over seven years. In fact, between 2013 and 2018 solar and wind energy generation was less than the observed generation in 2012.

Other relevant examples comprise cases that have only recently deployed solar and wind energy but at very low rates despite their specific conditions. South Africa is an important case to discuss under-performing. The country accelerated the expansion of wind and solar energy between 2013 and 2015, which pushed wind and solar generation from 0.01 percent to 2.3 percent, and since then have essentially decelerated. Both countries are also at opposing industrial structures with Spain a fully liberalised market and South Africa a national utility monopoly systemFigure 2-4. Shadow cases:

Figure 2-4. Shadow cases: Spain and South Africa



Given the diversity of conditions and regulatory solutions, I will utilise multiple indicators to assess the significance or curtailment and interconnection restrictions based on the following dimensions:

- Wind and solar energy generation share.
- Curtailment rates and business perception of curtailment risk.

- Economic burden of grid constraints for operation or for interconnection.

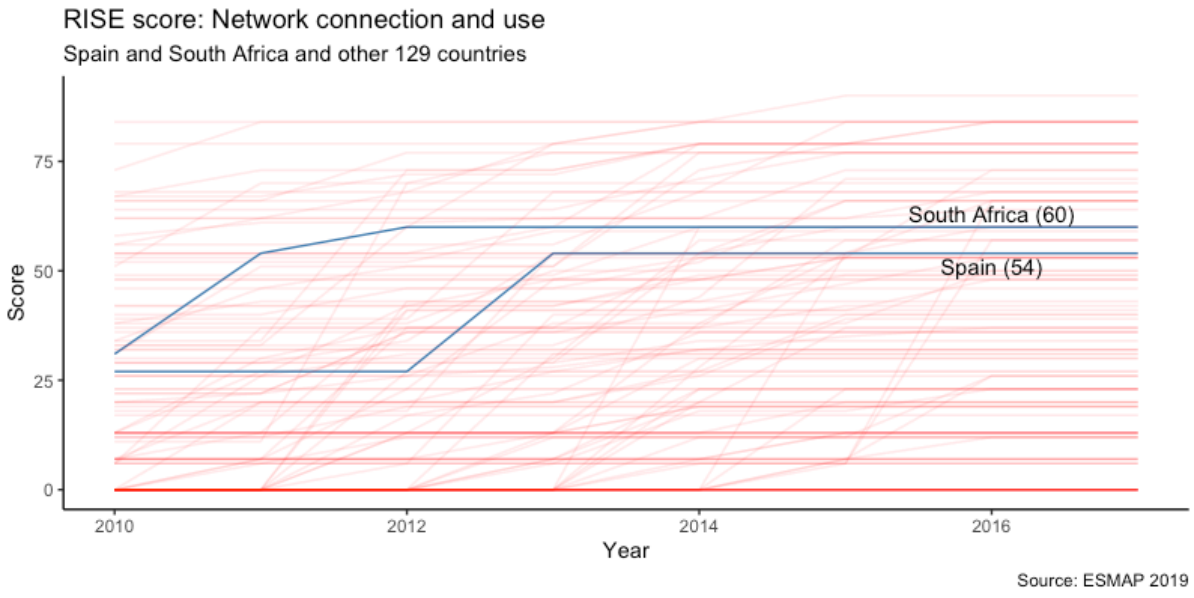
The trend of wind and solar energy generation share is the most direct indicator of achievement of the policy goal of renewable energy expansion. The OECD share has grown from 3 percent to 11 percent between 2010 and 2019 with yearly growth of only 0.8 points during the last five years. At this rate 2040 would mean a contribution of wind and solar still below 20 per cent. The growth of the share of wind and solar could develop far beyond 1 point a year. In Mexico, for example, achieving a 35 per cent clean energy goal by 2024 means a growth in the share of participation beyond 1.5 points a year.

Curtailment is the practice to cut-down wind and solar energy generation that could be delivered to the electricity grid at any particular time. [7] Regulatory authorities have allowed system operators to curtail solar and wind power generation when it is not possible to accommodate all the potential generation from the increasing installed capacity (Bird et al., 2016; Joos & Staffell, 2018; Olson, Jones, Hart, & Hargreaves, 2014; Qi, Dong, Dong, & Huang, 2018; Yasuda et al., 2015). Curtailment imposes a cost on generators, consumers or the government depending on the compensation regime for the revenue lost in cutting-off this zero-marginal cost energy. Simultaneously, curtailment can be a tool to avoid other events which could trigger the interruption of service, as explained by Olson et al. "the system operator uses renewable curtailment as a proactive operating strategy to meet ramping needs and avoid loss of load" (2014, 54). Curtailment might still be better than a regulatory imposed curfew on renewable energy investment. Administrative curfews or disincentives mechanisms have been placed in China, United Kingdom and Mexico for specific geographies and periods as national policies.

[7] I follow Bird et al. (2016): "We use the term curtailment broadly to refer to the use of less wind or solar power than is potentially available at a given time"; and Luo et al. (2016) "In China, the wind curtailment mainly refers to the phenomenon that the wind power is not put on the grid and the wind turbines have to be shut down because of the safety, technology, grid access management, system and other reasons".

Interconnection limitations refer to the administrative conditions in place for the placement of a renewable energy project and its physical interconnection to the public grid, which is necessary for any project that is not intended to be entirely for self-consumption. I use business opinion, captured by institutional scores and interviewees to assess the significance of interconnection barriers rely on business opinion. The World Bank Regulatory Indicators for Sustainable Energy show that while there is a global trend to facilitate interconnection, there are meaningful variances, and this variance might explain the general trends in the expansion of renewable energy. Figure 2-5 shows the evolution of this score for the cases of Spain and South Africa, for the period 2010 to 2017, which show a halt in the improvement around 2012 and 2013. This signals that in this regard both jurisdictions have made no relevant regulatory innovation over the management of grid interconnection.

Figure 2-5. Interconnection scores for shadow cases



Short-term curtailment and grid interconnection limitation might be useful instruments for managing power system operation and expansion, but they can also erode the business case for sustained investment if curtailment and restrictions are too high according to business expectations. In addition, they might raise the cost to consumers and the government. When

statistics were not available, I made an additional effort during the interviews to get opinions from businesses and advocacy organisations. I refrain from relying on regulators to assess the effectiveness of the regulatory framework due to their interest in representing their work in a positive light.

The following chapters present my review of the evidence of state regulatory effectiveness in the four cases of study. It also places these findings in the specific context of the political economy challenges given the stakes of asset owners in each particular context. After this discussion the fourth and fifth chapter will address the empirical evidence to evaluate the brokers hypothesis.

3 Political goals, economic stakes and regulatory outcomes

Assessing the quality of regulatory outcomes and gauging the relevance of regulatory innovations is difficult. Econometric analysis utilises panel data to draw conclusions on specific relations between institutional features and outcomes such as energy prices, investment in innovation, or environmental outcomes. This research attempts to study rule-making and regulatory outcomes that are specific to each country context. Therefore, I utilise a combination of indicators, from energy generation statistics to business opinions on the effective deployment of wind and solar energy.

This chapter provides a description of the regulatory outcomes I seek to explain. This is an effort in descriptive inference of regulatory outcomes I use as the dependent variable. These descriptions are not summed up into a single number or index that is directly comparable. Rather I provide a nuanced evaluation of each country's regulatory evolution and an abstraction of the economic stakes of asset-owners that define country-specific institutional, economic and political legacies.

The difference between Chile and the UK is not sufficiently contrasting to label one as better than the other. Similarly, the differences between China and Mexico are not too stark, even though Mexico has not had a problem with curtailment throughout the period. The lack of contrast is due to improvements observed during the five years period, in particular in the case of China where the problem of curtailment was still very serious still in 2015 and 2016.

Table 1-4, which also serves as a heat map, provides a summary of the interpretation of available evidence regarding the trajectory of renewable energy growth, curtailment level and interconnection limitations. Each comparative subsection will discuss these dimensions in detail.

Table 3-1 Summary of signals of regulatory outcomes

	Wind and solar share 2015-2019	Curtailment level	Interconnection limitations
China	3.9% → 8.7%	Very high → Moderate	Moderate
Mexico	2.9% → 8.6%	Low	Moderate
Chile	4.5% → 13.3%	High → Moderate	Moderate → Low
UK	14.1% → 24.5%	Moderate	High

The discussion is divided into five sections. The first provides a general comparison of the state of affairs in all four cases in relation to relevant global or regional averages. The next two sections describe the status of deployment of wind and solar, for liberal systems and then for state-dominated systems. This is followed by a discussion of the industrial structure of the cases and a comparison of economic stakes that contextualises the particular regulatory challenges for each pair-wise comparison.

3.1 Political goals and general trends

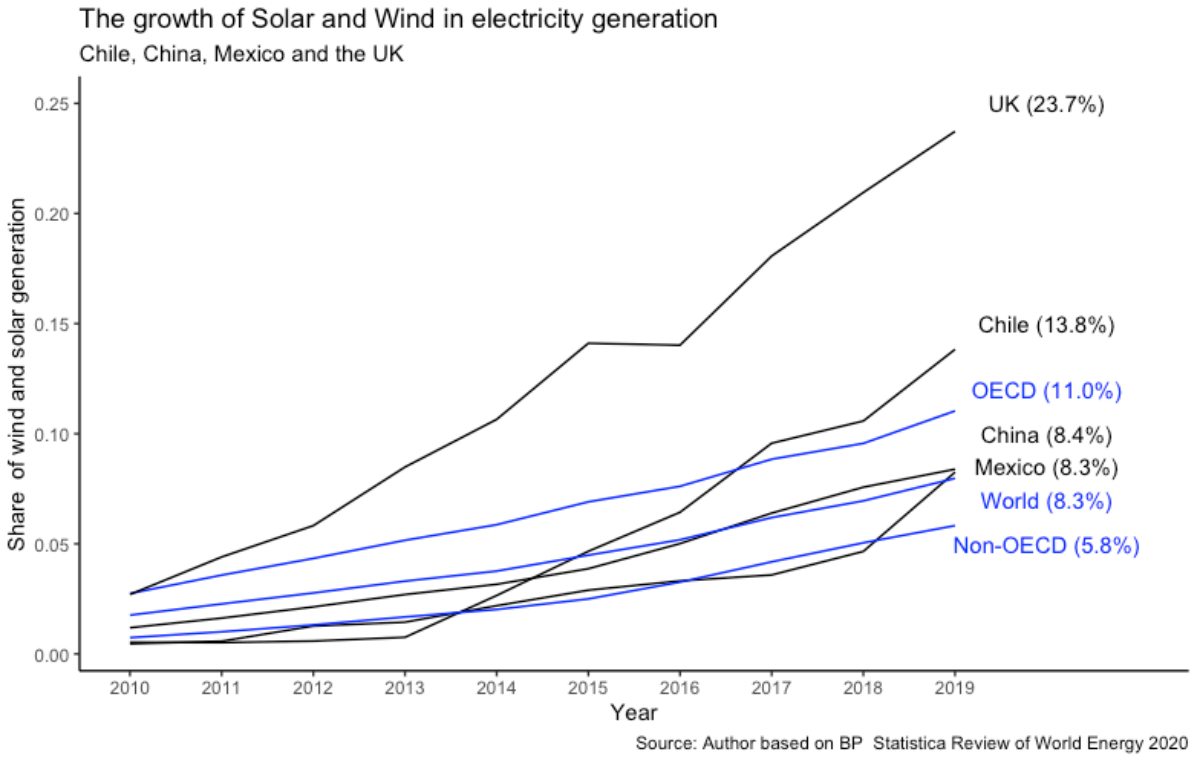
The cases under review all had renewable energy expansion targets at the time they were selected, in addition to 2030 emissions mitigation or reduction targets according to the Paris Agreement. As described in This is only a very broad depiction of regulatory success. Take for example the year 2015, in which the UK experienced zero growth. Despite the positive trend observed before, the sudden halt must have signalled a regulation-induced shock to the industry, which appears to have been corrected rapidly.

Figure *3-1*, for the last ten years the United Kingdom's combined wind and solar deployment has been significantly above the OECD average, and Chile surpassed the organisation members average wind and solar rate in 2017.

Mexico, also part of the OECD, is below that benchmark, and only in 2019 did it surpass the rate observed at global scale and within Non-OECD countries. During the last ten years, China remained slightly below and recently above the World average.

This is only a very broad depiction of regulatory success. Take for example the year 2015, in which the UK experienced zero growth. Despite the positive trend observed before, the sudden halt must have signalled a regulation-induced shock to the industry, which appears to have been corrected rapidly.

Figure 3-1 Wind and solar deployment in China, Mexico, Chile and the United Kingdom.

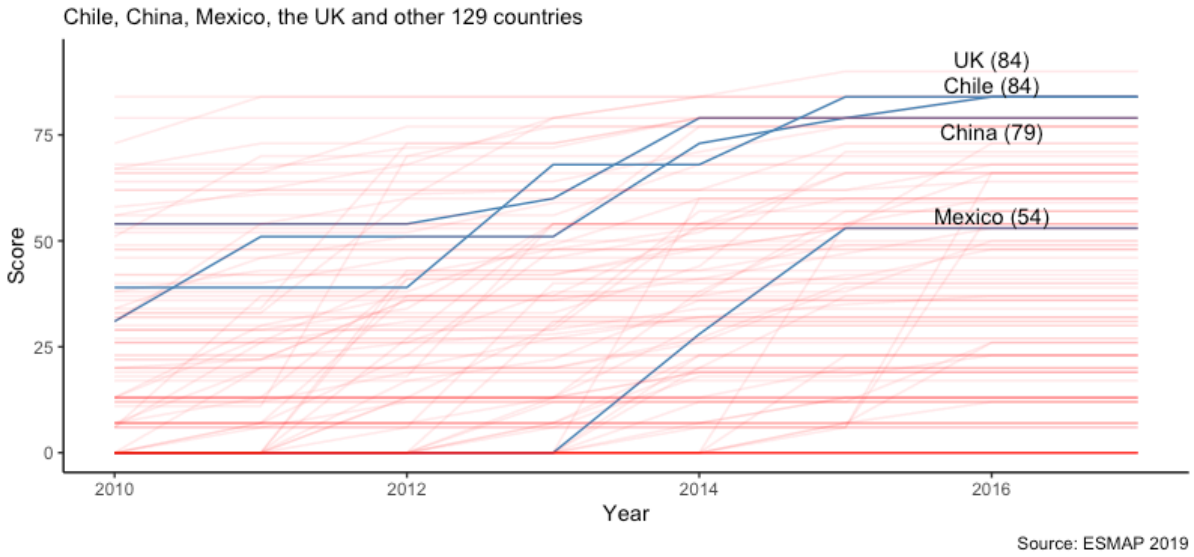


Source: Author based on BP 2019 and IEA 2020.

When compared to the two shadow cases briefly discusses in chapter 2, Spain or South Africa with stagnant growth, the four study cases have had a better trajectory of deployment of wind and solar

energy in the last decade. Furthermore, these jurisdictions have also made larger improvements on regulation for network connection and use as described by the World Bank's RISE scores in Figure 3-2. Mexico stands out as an outlier, both because it started from a score of zero, and because it remains well below the other scores. As the heatmap already presented, this is the area in which Mexico presents its main regulatory barrier.

Figure 3-2. Index for network connection and use (RISE)



Risk of curtailment is the other crucial indicator of the quality of regulatory outcomes. Under the curtailment risk perception metrics from Bloomberg New Energy Finance, both Chile and China have underachieved. However, the detailed quantitative and qualitative evidence shows that in both cases curtailment risk has been seriously reduced in 2019 and is not fully captured by the BNEF database. In the UK curtailment occurred on a significant scale but is increasingly compensated as part of balancing services and therefore its impact on business is less relevant. This nuance exemplifies why it is important to understand the specific context of regulatory options and economic stakes that provide meaning to these indicators.

3.2 Regulatory outcomes in liberal systems

Chile has managed the rapid renewable energy growth more sustainably than the UK, where costs of integration have increased associated with regulatory limitations to the development of low-cost onshore wind energy. In summary:

a. Chile and the UK experienced positive trends of renewable energy expansion
b. Revenue loss from curtailment risk exposure in Chile has decreased and remains low in the UK
c. Chile improves the conditions for interconnection, while the UK has maintained severe limitations for interconnection

Chile and the UK experience a positive trend of expansion for renewable energy. In the last five years, Chile has tripled the share of its wind and solar power. The UK has also been able to increase the share of wind and solar energy for most of the 2010s. Chile recently managed to diminish the risk of curtailment and limitation to interconnection maintaining a sustained growth rate of solar and wind energy. The UK established a framework to compensate for curtailment. Still, there are significant geography-based limitation to interconnection that undermine the development of competitive renewable energy resources.

Table 3-2 Summary of signals of regulatory outcomes: liberal systems

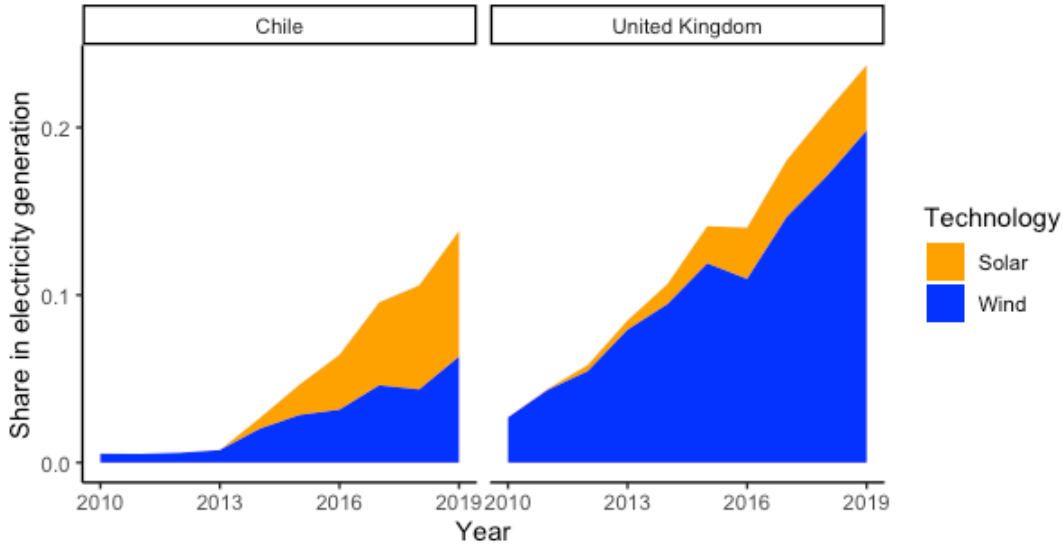
	Wind and solar share 2015-2019	Curtailment level/market risk	Interconnection limitations
Chile	4.5% → 13.3%	High → Moderate	Moderate → Low
UK	14.1% → 24.5%	Moderate → Low	High

As described in Table *3-2* the UK has maintained a steep growth in wind energy for most of the period. In 2019, wind accounted for 19.8 of electricity generation, and solar energy for an

additional 3.9 percent. Cost reduction in solar and wind technologies and the introduction of Contracts for Differences (CfD) are positive contributing conditions. Adverse conditions include interconnection limitations for generation at the distribution level, administrative limitations on onshore wind energy in England and Wales, and the exclusion of onshore wind from CfD auctions (Vivid Economics, 2019)(3B08, 3B09).

In Chile, the combined growth of solar and wind energy since 2013 is significant. In 2019 the total share of wind was 6.3 per cent, and the share of solar was 7.5 per cent. This growth was achieved through private investment for bilateral supply contracts and, since 2015, through central auctions for the regulated suppliers (IEA, 2018a). Historically, project development is affected by insufficient transmission infrastructure and the considerable market risk due to very low prices in critical nodes on the system (4A05, 4C06).

Figure 3-3. Solar and wind electricity generation in Chile and the UK (2010-2019)

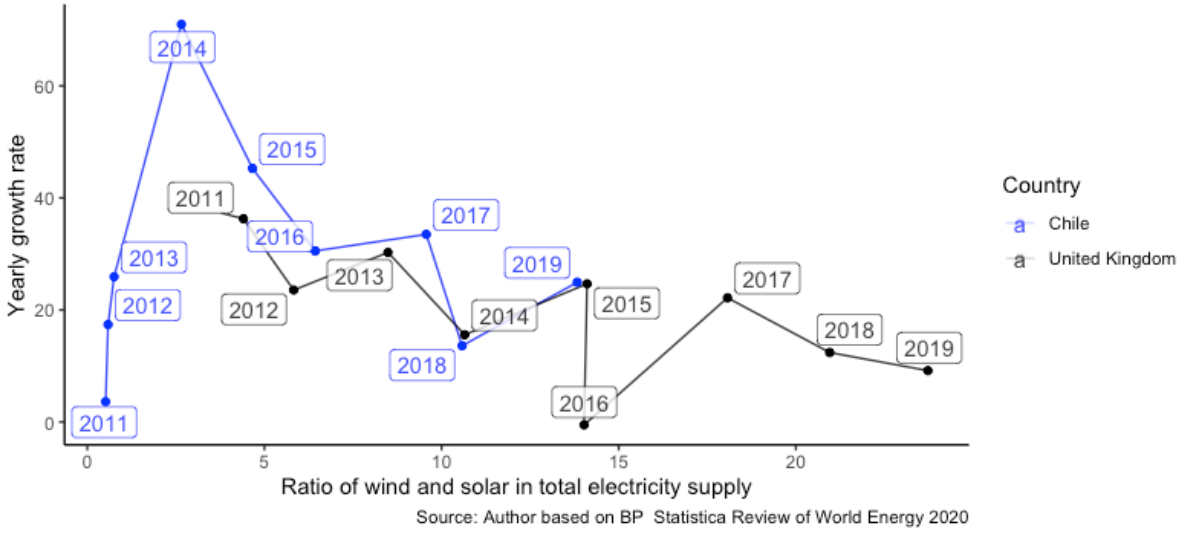


Source: Author based on BP Statistica Review of World Energy 2020

Figure 3-4 presents the ratio of wind and solar in total electricity supply, and its yearly growth rate. The figure shows Chile following the path of the UK with a five years lag. The expected expansion of solar and wind capacity in 2020 means that Chile might close the lag in one or two years. These parallel trends must be seen in light of electricity demand growth. Over the course of the decade,

electricity demand in the UK has diminished by 15 per cent, from 382 to 323 TWh. In contrast, electricity demand in Chile has grown 37 per cent, from 61 to 83 TWh. Relative to Chile, the UK would have required less infrastructure expansion. Between 2015 and 2019 Chile solar and wind power output grew by 2.3 times. In the comparable period between 2011 and 2015 in the UK, solar and wind power output increased by 1.9 times.

Figure 3-4. Growth rate and the share in total generation



The dimensions of curtailment risk and interconnection limitations are related because more stringent interconnection regulation facilitates grid operation and reduces the need for curtailment. According to the RISE network connection scores, Chile and the UK are equivalent, while there is no available BNEF curtailment risk score for the UK. Therefore, nuanced business opinion and academic assessments are part of this review.

A crucial risk for project development is lower than expected revenues from operation, which can happen due to uncompensated administrative curtailment. This unexpected loss of revenue can lead to bankruptcy for individual generators and to an increased investment risk for the industry. For Chile, the scores of curtailment risk estimated by BNEF fluctuated between high and moderate between 2017 and 2019. Fieldwork interviews corroborated that curtailment has been serious, even by accounts from authorities (4A03). While companies are encouraged to utilise bilateral contracts,

participate in central auctions and utilise other financial instruments to reduce risk of very low marginal prices, there are serious physical constraints due to insufficient transmission infrastructure (4B02, 4C05). But restriction to interconnection and a reduction of grid congestion have been progressively resolved by transmission infrastructure expansion and in particular the interconnection between the north and centre in 2019. Business leaders already consider congestion will remain a problem for the foreseeable future because the next expansion will not be completed until the end of 2020s (4B03, 4B04). In the past, insufficient transmission, grid congestion and low-marginal nodal prices meant bankruptcies and market exit from relevant renewable energy firms (4C05).

The problem of curtailment in the UK is also associated with grid congestion. Joos and Staffell (2018) estimated an average rate of curtailment at 10.6 percent, between 2012 and 2016 in Scotland, and 5.6 percent for all of Britain in 2016. However, the industrial stakeholders interviewed clarified that they consider that under the current balancing mechanism, renewable energy generators receive adequate compensation for dispatching down through a bidding process (3B05, 3B07). Compensation has reduced market risk and benefit incumbent wind energy generators, which also include incumbent generation companies like Scottish Power and EDF. In the last five years, the payments of re-dispatching paid to wind generator grew from 63.5 million pounds to 173.2 million pounds between 2015 and 2019 (National Grid ESO, n.d.). The limitations to interconnection in the UK have two instances. The first is the insufficient expansion of interconnection and of transmission capacity between wind-rich Scotland and demand-burdened England. The second instance is the administrative limitation to the development of onshore wind farms in England and Wales, the cheapest form of renewable energy. The exclusion of the technology from the CfD auctions compounds administrative limitations. The trade association Renewables UK estimates potential development of at least 35 GW that could reduce energy supply costs by 7 per cent in the next 15 years (Vivid Economics, 2019).

This interconnection limitation stand-out as a negative feature in the UK. However, in all other regards, the performance of the UK regulatory system is comparable to that of Chile. This means that the inferences from the comparisons cannot result from the variance in the outcomes, but rather from the comparison of mechanisms represented in the process tracing analysis.

3.3 Regulatory outcomes in state dominated systems

This section presents a review of regulatory outcomes. In summary, Mexico has managed the rapid renewable energy growth more sustainably than China. However, it is very important to stress that China was able to reduce the level of curtailment to internationally comparable levels between 2017 and 2019. Both China and Mexico experienced positive trends of renewable energy expansion. Revenue loss from curtailment is low in Mexico but remains a risk in China. And interconnection limitations increased in Mexico and remain relevant in China. The evidence is described as a heatmap in Table *3-3*.

Table 3-3 Summary of signals of regulatory outcomes: state-dominated systems

	Wind and solar share 2015-2019	Curtailment level/market	Interconnection limitations
China	3.9% → 8.7%	Very high → Moderate	Moderate
Mexico	2.9% → 8.6%	Low	Low → Moderate

In 2019, wind and solar energy accounted for 8.7 percent of electric power generation in China. Mexico reported 8.6 per cent for the same year. Both countries can claim a relative success on the integration of renewable energy, given their access to low-cost fossil fuels and demand growth rates. Curtailment has remained negligible during the decade in Mexico and China over-delivered its target for curtailment reduction in 2018 and 2019. These auspicious indicators exceeded expectations from two years earlier. Only in 2017, China still curtailed more than 10 percent of

variable renewable energy, and in that year Mexico's share of variable renewable energy was virtually stagnant at merely 3.5 per cent of total generation.

Electricity demand in China (7,170 TWh) stands at 20 times the demand of Mexico (339 TWh). However, the Mexican electricity system operator manages one of the largest interconnected electricity systems globally by the extension of the grid. To present renewable energy deployment in comparative perspective Figure 3-5 summarises the development of wind and solar energy in each country. The figure depicts the profile of growth of solar and wind generation at a yearly rate in contrast to its share within the total generation matrix.

Figure 3-5 shows short-term variations in the deployment of renewable energy and the long-term trend of expansion. Absent extreme economic events, policy changes explain large variations in growth rates. Variations are particularly evident in the deceleration of deployment in Mexico between 2014 and 2017, and acceleration between 2017 and 2019. Despite a positive outlook for wind and solar project development, the country is underperforming from the perspective of short and long-term policy goals. The country missed its 2012 renewable energy target, and then again, its 2018 renewable energy target of 25 percent clean energy by a wide margin of 5 percentage points.

In China during the 2010s, the growth of wind and solar installed capacity continuously surpassed the expectations of economic planners, but under very high levels of curtailment for most of the period. The 12th Five Year Plan renewable energy development program established a target of 100 GW of wind energy and 21 GW of solar PV for 2015. Wind energy reached 131 GW and solar energy 43 GW, far above the expected levels. For 2020, the 13th Five Years Plan defined a target of 210 GW for wind and 110 for solar PV. Wind installed capacity reached the target in 2019. Solar PV exceeded the target in 2017, and at the end of 2019 already reported 204 GW or 85 percent over the original target (NRDC, 2016; Wang & Tao, 2020).

As described in Figure 3-6 Mexico's renewable energy expansion data shows a rapid increase in wind and solar generation in 2019. Mexico experienced high fluctuations in the growth rate of wind and solar generation until 2016. But between 2017 and 2019 Mexico experienced a surge in wind and solar energy installation which tripled the amount of generation from 10 GWh in 2016 to 29 GWh in 2019. China also shows a certain amount of fluctuation, especially with the deceleration in 2014 and 2015. Yearly growth accelerated again in 2016 and 2017 and has decelerated since then.

Figure 3-5. Solar and wind electricity generation in China and Mexico (2010-2019)

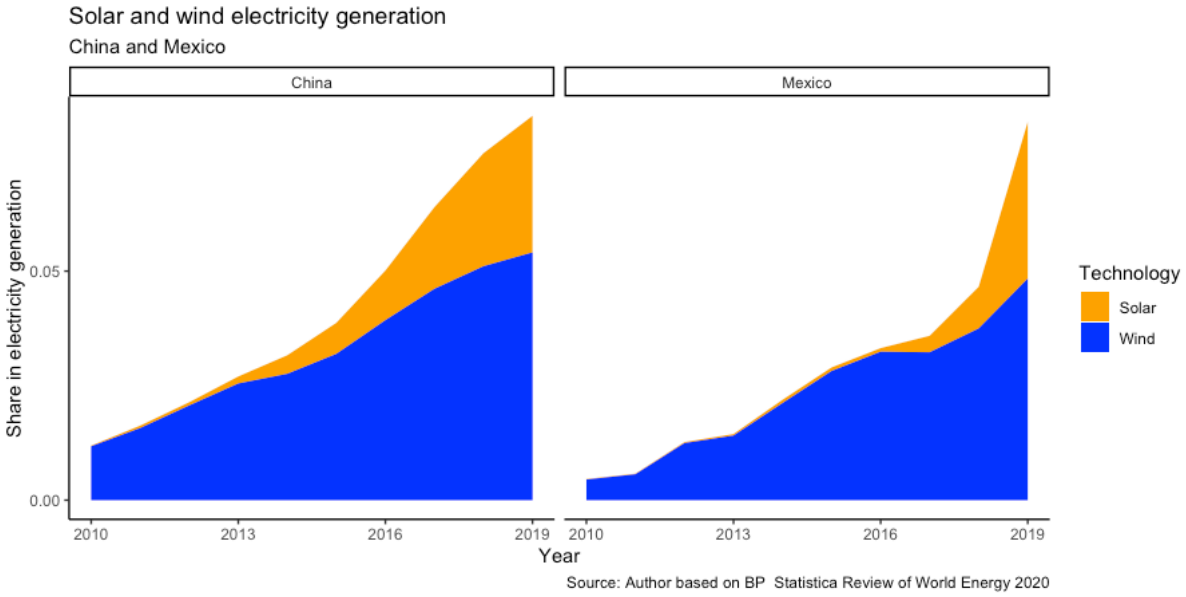
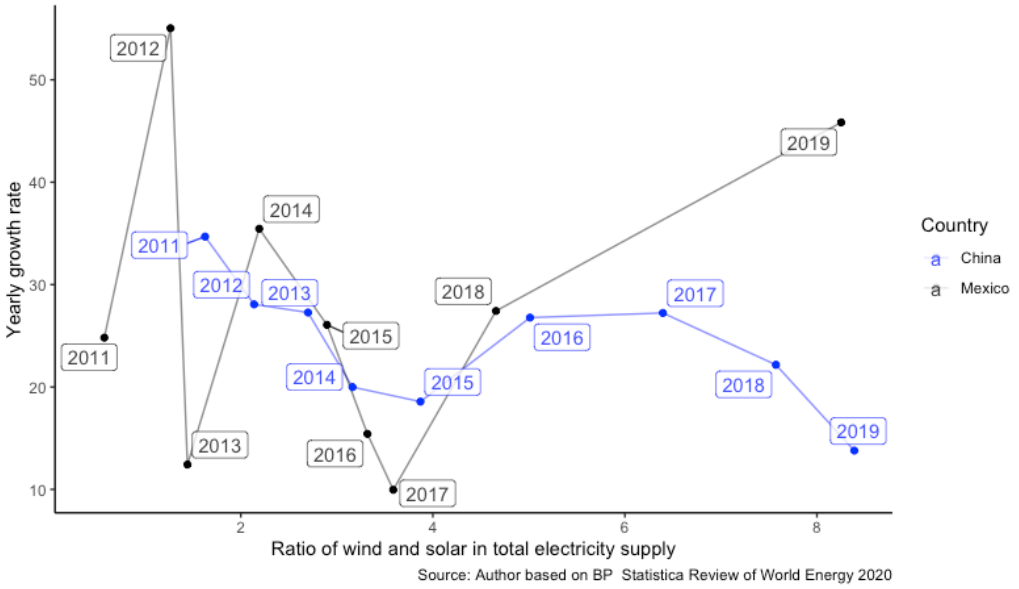


Figure 3-6. Growth rate and the share in total generation



Mexico and China have established multiple revenue guarantees to generators in the form of administrative reference prices in China, or a combination of independent power purchase agreements, subsidised bilateral contracts, and long-term auction contracts in Mexico. Thus, in these hybrid markets both incumbent and new generators have been little exposed to revenue uncertainty. However, wind and solar generation are exposed to risks of curtailment. Neither of the two countries pays compensation for wind and solar curtailment, even if their formal rules might justify the practice. Therefore, curtailment can have significant economic implications if individual power plants are systematically exposed to the loss of revenue.

In Mexico, curtailment of wind and solar energy is considered so low that is not reported by public regulators, nor by the private trade associations (1A01, 1A05, 1B05). BNEF (2019) reported low curtailment risks for three years in a row. And the industry interviewees reported few concerns about interconnection limitations, even though there are concerns about the slow development of transmission infrastructure (1B03, 1B04). The Market Monitor, however, has expressed concern that future episodes of systematic curtailment might not be registered with current methodologies (Monitor Independiente del Mercado, 2020).

Wind and solar curtailment in China has been regarded as a very serious lack resulting from compounding problems with infrastructure and institutional market design (Qi et al., 2018; Yuan, Zhang, Guo, Ai, & Zheng, 2019; Zhu et al., 2019). The scores for curtailment risk from BNEF (2019) remained at the highest level. The acceleration of the expansion of wind and solar capacity around 2015 represented a severe challenge to integration into the electricity system. Wind curtailment was already high at around 8 percent in 2013-2014 but doubled to peak at 17 per cent in 2016. Solar curtailment also reached a maximum of 11 percent in 2015. In the following years, curtailment rapidly diminished, especially in 2018-2019. The Five Year Plan incorporated generation references that implied higher average utilisation hours than historical rates and in 2018 the central government-imposed curtailment targets for the years 2018 to 2020 of 5 percent during the period for solar, and a decreasing target of 10 percent, 8 percent and 5 percent for wind (CNREC & ERI, 2019).

In 2019, authorities in China observed a curtailment rate of only 4 percent for wind and 2 percent for solar (Xinnan Wang & Tao, 2020). But despite this regulatory success future curtailment still remains a serious concern, as does the lack of insufficient revenues from the markets that are dominated by coal producers. In Mexico, throughout the period of study, the main concerns for renewable energy developers in Mexico, were insufficient interconnection capacity, especially for wind developers, or insufficient growth in central contracting mechanisms. These are all subjects where SOs and EOs can be crucial, but before discussing their specific role. I review the structure of the interests from asset-owning actors.

The review of the three dimensions for both cases shows Mexico om relatively better standing, primarily because of the lack of meaningful curtailment. However, the rapid reduction of curtailment in China between 2017 and 2019 shows improving regulatory outcomes and makes it impossible to claim that Mexico's regulatory outcomes are clearly better than those of China. As in the pair-wise comparison of liberal markets, the absence of two contrasting outcomes means

that inferences from the case comparison will derive from similarities and differences in the mechanisms that relate knowledge exchange to regulatory action. To better understand those processes it is important to describe the organisations of asset owners' economic stakes.

3.4 Economic stakes in liberal systems

Private asset-owners focus on expanding the market share where they face competition. Grid companies, for example, hold interest in steering new solutions to balance electricity systems to business lines they are allowed to participate in. Thus, asset-owners attempt to influence the regulatory framework to expand the products they can provide, while competing in providing those products that are already in the market, from electricity to grid lines or billing services.

In Chile, market liberalisation began under a military dictatorship committed to privatisation and the retrenchment of the state from asset-ownership, planning and even regulation. During the late 1990s and early 2000s, subsequent crises from scarce water resources and limitation of gas supply from Argentina precipitated regulatory revisions and conflicts regarding the dominant position of asset-owners. During this period, there has been a growing fragmentation of the industry, enforced by legal reforms or through the arrival of new market entrants through foreign investment and acquisition. Industrial reorganisation for competition was a protracted process. Dispatching centres were created in 1985, but it was not until the early 2000s when the major utility, ENDESA, divested its transmission infrastructure – and not without political and judicial conflict. It must be noted that in contrast to what is a common understanding in the 2020s electricity systems, for most of the protracted evolution transmission was not considered a public service (Botfeld Gerlach & Concha Mandujano, n.d.). Most of the concerns have been based on the ability of incumbent asset owners to extract handsome gains from the industry. This is one of the reasons why, in response to major social unrest in 2019, the government moved to revise down the long-term return rate of companies and negotiated packages that would immediately reduce the cost of electricity services in the country (Sánchez Molina, 2019).

The logic of governance changed in 2015, when the reforms enforced the unbundling of the dispatching centres from the private asset owner to incorporate a public independent system operator (SO), the Coordinador Eléctrico in Spanish. In terms of the industrial structure, this is reflected in the creation of a SO that is independent from the transmission and generation asset owners. But already by 2015, the industry in Chile had a very different landscape due to the successful contestation for transmission development and generation projects development. The growing role of a central procurement agent for transmissions infrastructure and long-term generation contracts only accelerated the trend.

The UK reform followed a similar path to that of Chile. During the 1980s the government advanced a number of structural reforms that introduced wholesale market pools and the progressive privatisation of state assets. Reform in the UK starts with the Electricity Act of 1989. The model introduced wholesale competition and the regulation of monopolies for transmission and distributions. In Great Britain, National Grid and Scottish Power were the dominant firms, while Scottish Power also retained assets in distribution, retail and generation. By the end of the 1990s, further reforms introduced retail competition and allowed further fragmentation of the market structure. Increased fragmentation and the emergence of a balancing market in place of a pool market led regulators to revise the National Grid license and create a new stand-alone settlement manager in the form of Elexon, as a company formally owned by the National Grid but legally independent.

The concerns throughout the period were also similar to those of Chile, especially the market power from the largest incumbents in the early phases and the lack of efficiency gains that benefited the final consumers. Recent concerns arise from the lack of mechanisms to assess the need for, and secure the investment in, low carbon technology energy and grid infrastructure (IET & Energy Systems Catapult, 2016). The government has deployed instruments for de-risking investment in new assets in the form of renewable energy obligations and feed-in tariffs first in

the 200s, and the Contract for Difference system later on in the 2010s. License revisions separated the system operators as an autonomous unit within the National Grid And with the specific mandate, amongst other, of delegating the role of building a "whole system perspective" (BEIS et al., 2017).

Table 3-4 presents a summary of key interests from different industrial actors, all of them commercial asset owners, except for SOs. The most salient difference in the organisation of the industry is Chile's state control over the SO and limited competition in retail. But in general, the structure of asset-owners' interests are similar. Asset owners want to maintain appropriate return rates from existing assets and expand their share of the revenues in the industry. Actors can expand their share of revenues by expanding their market share in competition, or by ensuring that new products are placed within their market segments. For example, a grid company might prefer to be paid for investing in frequency control equipment, rather than frequency control to be considered as a product in markets where they cannot participate.

In 2019, when most of the empirical research was conducted, both jurisdictions had a very clear horizon for decarbonisation of electricity. Asset-owners were not interested in opposing the expansion of renewable energy, but rather on maximising their share of the revenues in a changing market. In both Chile and the UK large-scale generators turn to the development of renewable energy project, in part underpinned by the new auctions system that provide price guarantees. However, companies with natural gas assets in the UK and coal plants in Chile would manoeuvre to sustain a revenue base by maintaining dispatched hours or receiving other forms of compensations, for example, capacity payments or ancillary service markets.

Table 3-4. Industrial structure and actor interest in Chile and Britain in 2019

Segment	Actors	Control	Governance mechanism	Asset owning interests
		Chile		
Generation	Gencos	Non-state	Market competition	Expand market share Maintain return from assets

SO	Coordinador (ISO)	State	Regulated monopolies	NA
Transmission	Transelec and other trans Co.	Non-state		Expand revenues from grid infrastructure Fulfil reliability obligations
Distribution	Discos			
Retail				Expand market share
	Bilateral supply		Market competition	
Britain				
Generation	Gencos	Non-state	Market competition	Expand market share Maintain return from assets
SO	National Grid ESO (SO)		Regulated monopolies	NA
Transmission	National Grid, Scott.P, Scott.H			Expand revenues from grid infrastructure Fulfil reliability obligations
Distribution	Discos			
Retail	Retailcos		Market competition	Expand market share Expand market products

Therefore, the critical political and regulatory debate is not on whether to expand renewable energy, but rather on what markets and products are remunerated, and who can participate in those markets. Transelec, Chile's largest transmission company, prefers regulators to scrap existing legal separation obligations for them to invest in new markets, on assets like storage or distribution-level services (Botfeld Gerlach & Concha Mandujano, n.d.).

The regulatory decisions over interconnection and balancing have an economic distributional effect. In fact, it is the regulators who established the distribution of costs amongst market players. In the UK, consumers have taken on the burden of multiple mechanisms to finance renewable energy expansion and system integration, including CfD of offshore wind energy and the costs of re-dispatching wind energy as a balancing service. In addition, a significant concern has been the potential for incumbent companies in the grid business to maintain revenues from their existing business lines, including those in competing industries like natural gas transportation and the continental interconnectors.

The expansion of wind and solar energy in the UK has been constant, with the exception of 2016, but the costs of grid congestion and the expansion of offshore wind have been paid by consumers. In Chile, consumers have been spared from financing the costs of renewable energy expansion, and regulators have improved the conditions for interconnection and operation by reducing grid congestion.

The concerns in Chile are not altogether different. Local stakeholders are concerned about incumbent generators' interest in maintaining the value of a coal power generation portfolio, including by preserving utilisation hours and additional payment in markets, for example, through flexible operation payment. The SO can curtail wind and solar generation with no compensation. And projects are exposed to marginal prices at zero. In parallel, incumbent fossil fuel power plants experience changes in operational schedules that increase their cost due to low efficiencies from ramping (4A04). Incumbent generators have called for specific flexibility payments to existing power plants to cover these additional costs. This has started a new wave of regulatory battles on market products for the remuneration of flexibility, documented in the generators trade association proposals (Generadoras de Chile, 2020; Moray PSR, 2018).

3.5 Economic stakes in state dominated systems

The industrial structure in state-dominated systems is defined by the formal rules for separations between business and segments with or without competition, but also by the nature of revenue streams. In these markets the use of revenue guarantees is widespread. Generators might have long-term contracts with public utilities paid at benchmark prices rather than experiencing market price risks. Furthermore, state-owned companies might have softer investment budgets and respond to policy goals. These characteristics define the asset base and, therefore, the stakes companies have on the integration of renewable energy.

In Mexico, multiple failed attempts at swift liberalisation preceded the 2013 power sector reform, in contrast to other sectors that had experienced rapid privatisation in the 1990s. The power sector experienced a slow transition process, from the 1992 *Ley del Servicio Público de Energía Eléctrica* (LSPEE) to the constitutional reforms in 2013, and the publication of the *Ley de Industria Eléctrica* (LIE) in the summer of 2014 that superseded LSPEE (Carreón-Rodríguez, Jiménez, and Rosellón 2006).

By time of the 2013-2015 reform, Mexico had already approved a General Law on Climate Change (2012), including clean energy targets of 35 percent of generation by 2024, increased from around 15 percent. International institutions and policy think-thanks applauded the 2013-15 reform as a feat of liberalisation, with the introduction of wholesale market competition the unbundling of the state-owned company, and the creation of an independent system operator (Alvarez et al., 2015; IEA, 2017). The state-owned company, CFE, was created businesses units for transmission, distribution, regulated retail, non-regulated retail and six generation companies.

The depth of reform that took place between 2013 and 2014 is particularly prominent concerning generation. All generators have to rely on the wholesale market, either pooling energy in day-ahead and real-time markets, or by taking part in financial commitments for load-serving through bilateral contracts (IEA, 2017). The retail business experiences few reforms. CFE maintained retail services to all small consumers under regulated tariffs. The system operator unbundled in 2014 keeping its name, the National Centre of Energy Control (CENACE) and physical infrastructure. As a government agency, CENACE has technical and administrative independence, yet it is hierarchically under the Ministry, SENER.

For the last three decades, China has experienced a continuous revision of the governance and industrial organisation model of the country. Despite many changes, the current structure was defined most clearly in the early 2000s built to provide high guarantees to investors in the face of cycles of underinvestment for periods of rapid demand growth (Davidson, 2018; Xu, 2017; Yuan,

Guo, et al., 2019; S. Zhang, Andrews-Speed, & Li, 2018). The model relied on the selective expansion of liberalisation features to accelerate investment in generation capacity under an industry-led governance system, based on industrial actors' agency to compete for market share guided by goals established by the central and provincial government. Companies and provincial-level governments could exploit the lack of central government electric power system planning and the significant devolution of planning and operational supervision to provinces.

The introduction of liberalisation features in the 2000s focused on corporatisation and competition between firms, with little commitment to strong quality of service, competition or environmental regulation (Tsai, 2014; H. Zhang, 2019). The unbundling of a single national utility created several national generation companies, three grid companies, as well as two engineering and design institutes. The grid companies, the State Grid Corporation of China, the Southern China Grid Corporation and the Inner Mongolia Grid Corporation are also monopoly retailers in their region of control. Traditionally, their revenue comes from the difference between bulk energy prices and retail tariffs, and only more recently from wheeling electricity for inter-provincial transmission. The reforms from the 2015-17 increased centralisation at the dispatching centres in Beijing (for the control area of the State Grid) and Guangzhou (for the control area China Southern Grid). Power exchange centres have also gained certain autonomy and centralisation in Beijing and Guangzhou.

Since the 2015 mandate for reforms, and particularly after the 2017 mandate for reforming the dispatching system, the share of planned dispatching is progressively reduced to make room for operators engaging in bilateral contracts or wholesale market competition (2C08)(Yuan, Guo, et al., 2019). This form of liberalisation should not be seen as a solution to the problem of renewable integration. As some interviewees pointed out, the concern is that in the future, bilateral contracts will be used to lock-in fossil fuel generation (2C08). And more generally, there is concern over the

introduction of market solutions that would benefit incumbent fossil fuel generation (S. Zhang et al., 2018).

Table *3-5* provides a summary of the current industrial structure for both Mexico and China. A significant difference between Mexico and China is Mexico's concentrated ownership in one state-owned company, CFE, in contrast to China's central government ownership of several companies that can therefore compete between themselves.

Table 3-5. Industrial structure and actor interest in Mexico and China in 2018

Segment	Actors	Control	Governance mechanism	Asset owning interests
Mexico				
Generation	CFE	State	Market competition	Expand market share Maintain return from assets
	Private Gencos; IPP; Self-supply	Private		
System Operation	CENACE (ISO)	State	Regulated monopolies	NA
Transmission	CFE			Expand revenues from grid infrastructure Fulfil reliability obligations
Distribution				
Retail	CFE Supply			Expand market share
	Private Retailcos	Private	Market competition	
China				
Generation	Central gov owned Gen Co.	National	Market competition	Expand market share Maintain return from assets Secure best locations for solar and wind projects
	Locally owned and private Gen Co.	Sub-national & private		
System Operation	SG-BJ dispatch centre SCG- GD dispatch centre	National	Regulated monopolies	Not applicable
Transmission	SG, SCG, IMG			Expand revenues from grid infrastructure Fulfil reliability and curtailment obligations
Distribution				
Retail	SG, SG, IMG	National		Expand market share

	Self-supply and bilateral supply	Sub-national	Market competition

However, one of the most relevant findings in the literature is that incumbent generator companies had, for a long time, seen solar and wind energy technologies as an additional business opportunity. The renewable energy markets were pushed by the central government through tariff subsidy or financial subsidy vehicles. Whilst there was a small market for renewable energy, the incumbent thermal generation companies entered and developed the market, competing for their share in the segment (Davidson, Kahrl, & Karplus, 2017; Zhu et al., 2019). Zhu *et al.* (2019) provide evidence that the large state-owned generation companies are competing for renewable energy market share, local subsidies and the best locations for projects. Companies assume a market risk, and internally might even misrepresent the risk, in order to secure projects to move ahead, despite the high potential of relevant curtailment to harm the earning on the project for a few years. Companies might have underestimated to the actual impact of curtailment, but that the logic of market share competition is sound. In retrospect, observing the low rates of curtailment in 2019, this seemed like a viable strategy; losing revenue for a few years might be an acceptable price to pay for the right location and grid access in the years to come.

The literature on energy policy in Mexico has argued that the reforms overcame the major barriers to the expansion of renewable energy in Mexico, mainly the lack of willingness from the state-owned company to invest or purchase wind and solar energy, and the lack of an open market for bilateral contracts and insufficient transmission infrastructure (Wood, 2018). Under these conditions, private renewable energy developers had limited opportunities to find suitable purchase contracts, and when they did, they faced significant delays or costs to interconnect (Hernández, 2006; Hernández Ochoa, 2018; IEA, 2017).

The reform also allowed the government to take the interconnection approval procedures and the grid expansion planning away from the state-owned company. These measures were achieved through the independence of the system operator. CENACE has a mandate to not discriminate

against renewable energy generators. Along with these changes, the government established a new system for renewable energy auctions that enabled the entrance of new power generators. The conditions have favoured the expansion of renewable energy, reduced the limitation to interconnection and risk of revenue insufficiency. However, the priority of development in the country was to expand electricity generation from natural gas.

Recent investment evolution has meant that while the private sector expanded its presence in generation assets including in renewable energy, CFE focused on the expansion of natural gas wholesale business. Simultaneously, virtually all new renewable energy projects by the company were cancelled or postponed.[8] As reported by informant 1B10, all of the new business opportunities were based on the expansion of natural gas combine cycles power plants, throughout the entire country. Only one subsidiary has attempted to develop non-hydro renewable energy projects with no success. Advanced projects for wind energy in the wind-rich region of Oaxaca were cancelled (1B05).[9] This change in the industrial configuration was a policy preference fulfilled by the stat-owned company which exemplifies the relevance of the link between state-ownership and policy goals to define the structure and distribution of the asset base in the country.

3.6 Outcomes, stakes and knowledge exchange

This chapter provided a comprehensive description of regulatory outcomes in the four case studies. The pairwise comparison does not show significant contrast that could serve as a basis for empirical inferences. All four jurisdictions show significant improvements over the period. Each case's regulatory successes offer an opportunity to understand the mechanisms and specific conditions under which regulators work.

[8] There is one exception of a single geothermal power plant directly financed and instructed by SENER.

[9] Former Under-secretary for Electricity Cesar Hernández points a number of renewable energy projects cancelled for "diverse reasons" in a footnote of his official recollection (Hernández Ochoa, 2018).

The following two chapter will focus on the instances of regulatory innovation that explain, for example, how the UK accelerated growth of renewable energy after the halt in 2016, how Chile maintained a steady pace despite the power of incumbent asset-owners in coal, how China reduced curtailment after 2017, and how Mexico was able to finally accelerate wind and solar deployment after 2017.

Regulatory action depends on overcoming the type of knowledge asymmetry that is defined by the structure of the industry and the stakes of asset owners. This chapter also argues that historical developments show that asset-owners are not necessarily against the expansion of renewable energy, as long as this opens new markets where they can hold valuable revenue streams, either as generators of renewable energy or owners of grid infrastructure and other technologies for electricity services. Asset-owners will attempt to drive the market design to serve their preferred business line, which might result in an inappropriate distribution of economic burden, for example, through uncompensated curtailment affecting renewable generators, or excessive use of compensating curtailment affecting consumer rates.

The instances of regulatory innovation are grouped into three areas: market reforms, central contracting, and planning. Regulatory action meets asset owner diverse preferences in these particular areas as they define the present and future of the revenue base of companies. Market reforms define the market products and modes of competition and remuneration. Central contracting provides opportunities to lock-in revenues backed by government fiscal budget for regulatory intervention. Planning instruments define the future of investment opportunities in infrastructure with the potential or steering investment away or towards a particular market. The following chapters will refer to these challenges and regulatory innovations as part of the process-tracing analysis. But to do that each chapter will first identify the structure of knowledge exchange in the regulatory ecosystem.

4 Knowledge brokers in liberal markets

In liberal regimes regulators set the rules for markets and monitor compliance by all players under the assumption that motives of gain and competition serve as the primary mechanisms to keep participants in check and increase cost efficiencies. From a historical point of view, the UK and Chile countries are in a phase characterised by the expansion of government-guidance and centralised decision making. The challenge for these regimes is to fit new roles of central coordination into decentralised private decision making (IET & ES Catapult, 2016; Rhys, 2018). But from the perspective of preserving markets mechanisms, centralisation and government intervention are only devices to support the transition between different technological configurations (Helm, 2017; Keay & Robinson, 2019).

This chapter compares electricity governance in Chile and the United Kingdom, two economies recognised as spearheading legal reforms to privatise the electricity industry and create markets since the 1980s. Both countries have committed to achieving net-zero emission by 2050, and the existing research commissioned by each government shows the need for the virtual decarbonisation of electricity within three decades (Ministerio de Energía, 2019; National Grid ESO, 2020). The positive trends in renewable energy deployment provide extensive credibility to the commitments of decarbonisation in the electricity industry.

This comparison provides evidence of the relative relevance of knowledge brokers in facilitating rulemaking for effective renewable energy deployment. The evidence shows that knowledge brokers assumed critical roles in improving the regulatory marking, in particular in areas where

liberal regulators had been previously absent, such as long-term planning, the coordination of private investment, or the centralisation in government of investment choices.

System operators (SO) have become increasingly important in leading processes of regulatory and operational experimentation on behalf of regulators. Expert organisations (EO) contribute knowledge that is vital to regulation, independently from specific incumbent industries. For instance, SOs and EOs modelling that shows the potential economic savings of closing down a coal power plant and its feasibility. But SOs and EOs contribution are more significant when governments formally enlist their support by providing them with explicit mandates or offering robust funding to carry out with their work.

The process tracing showed that the relevance of SOs and EOs is not only based on pre-existing expertise but also resulted from the delegation of authority from the official public regulators. EOs, like the Universidad de Chile or The Catapult in the UK, have a pool of particular expertise which they developed only because of roles assigned to them in the process of regulatory decisions making. That is why they build software, models and tools for long-term planning. Therefore, there is a feedback loop of expertise, delegated authority and the pooling of regulatory capacity.

The research also shows that the importance of any particular broker of knowledge is progressively diluted. This happens due to two reasons. The first is that regulators develop their expertise and capabilities by internalising the functions of EOs. And the second is the diffusion and codification of what might have been scarce knowledge so that a growing number of actors are able to provide knowledge.

This chapter discusses the evidence from the historical review, network analysis and process tracing with the following structure. Firstly, I review the theoretical framework as it applies to liberal markets. Secondly, I describe regulatory ecosystems based on historical analysis and network elicitation. I then dedicate three sections to the discussion of the findings on the role of

SOs, domestic EOs and foreign EOs. The chapter concludes with a summary of comparative conclusions.

4.1 The theoretical framework for regulatory governance in liberal regimes

The logic of governing markets through regulation is that states provide predictable rules for agents to interact in markets or provide clear performance standards. Rules should be indifferent towards business choices on technology and operation. However, in practice, electric market design and incentives-regulation correspond to specific technological configurations.

Since the inception of liberal electricity markets, the regulatory choices have been associated primarily with thermal power systems (Borenstein, Severin; Bushnell, 2015; Lambert, 2015; D. Victor & Heller, 2008). Regulators are migrating between technological landscapes once again. In this transition, regulators need to protect the legacy of business commitments and simultaneously incentivise investment and efficient operation for the expansion of zero short-term marginal costs power generation plants.

Incumbent asset owners can delay and disrupt transition and if they have embraced low-carbon assets, they will attempt to orient regulation to favour its business preferences even within the new technological landscape (Colgan, Green, & Hale, 2020; F. Geels et al., 2019). Liberal market regimes pool asset owner and other stakeholders' opinions as the basis for any regulatory decisions. Incumbents participate in decision making indirectly through their voice in regulatory processes, or directly when they are allowed to make decisions on behalf of the industry, as it was common for gid companies.

In liberal regimes, assets are already exposed to different levels of market risk. Still, the change in technological configuration might compound the risk and accelerate the loss of value of their assets. The growing salience of alternatives in infrastructure choices means this is at the forefront of debates. For instance, in the UK, there is concern about the historical preference for international interconnectors with continental Europe, which is an unregulated business of the

National Grid Company (3B05). As expressed by the trading unit of EDF in regulatory consultations: "We have previously noted potential conflicts of interest between National Grid's electricity interconnectors business, for instance, and the role of the System Operator" (EDF Trading, 2017). In Chile, there was significant concern about a market design in which only but a few companies with contracts to retail suppliers and large consumers could manage the market risk of solar and wind energy projects (4C06), and there is significant debate over the right combination of transmission expansion and local storage facilities needed to manage wind and solar peak production. In both cases, incumbent actors have attempted to stir regulatory design to capture revenues from new markets for infrastructure and flexibility services.

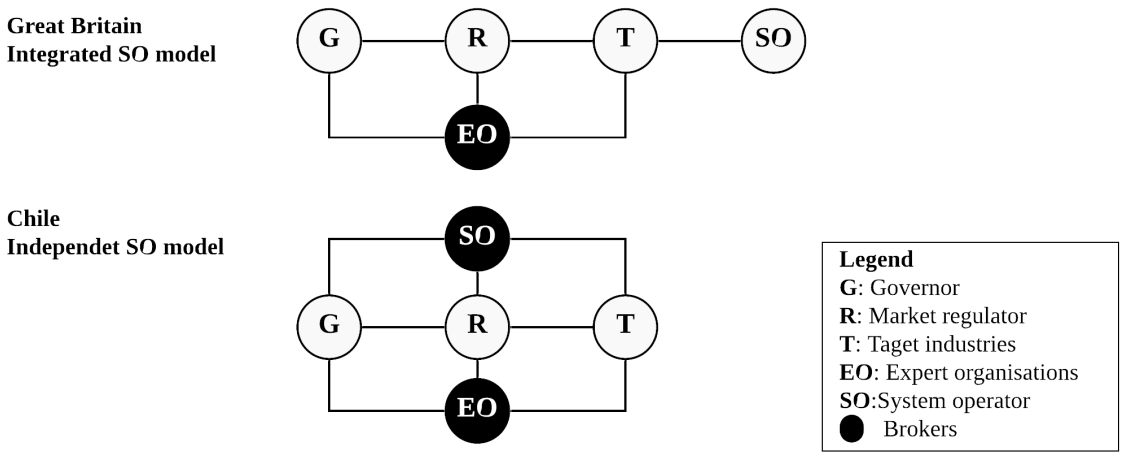
For market design scholars, like Joskow (2014) and Wolak (2014), regulators benefit from engineering consultants and ecosystems where stakeholders and expert organisations can contribute to monitoring compliance from the target industry. Liberal markets rely on external sources of expertise as a matter of course, but the assumption is that these sources or expertise are abundant. This thesis research hypothesis supplements market design scholar's recognition of the need for expertise external to asset-owners by proposing that these sources of external expertise can also be scarce. Regulators build or take advantage of institutional arrangements to acquire this expertise, and the various structures for expertise acquisition have political consequences, as these structures might reduce or simply reproduce the asymmetry between the regulators and the industry.

Non-asset owning actors, like the system operator (SO) and expert organisations (EO) allow regulators to obtain additional expertise and triangulate evidence provided by the industry. Additional sources of knowledge enable the regulators to distinguish between that which is relevant and useful for public regulation, and that which promotes the interests of asset-owners. Independent SO have interests and preferences, as would a research team in a prestigious

university, and even consultants. However, regulators would expect these not to be aligned with the interests of a particular asset owner.

Chile and the UK differ in one specific institutional feature, the position of the system operator, either as a public agency or an office dependent of a grid company. The models of indirect governance reproduced in *Figure 4-1* establish a clear distinction between models and without system operators. Chile rapidly moved between models from 2015 to 2017, while the UK moved only partially to concede more autonomy to the SO between 2018 and 2019. Chile very clearly conforms to the model of the independent system operator, and the UK represents the model of the transmission system operator with incentives regulation framework for the SO.

Figure 4-1. Models of indirect governance in liberalised electricity systems



Source: Author.

My argument is that the local regulatory strength depends on the presence of EOs and SOs that are independent from asset owners. The presence of a public independent SO would allow Chile to better manage the problems of renewable energy expansion than the UK. Additionally, the relative robustness of an ecosystem of EO would also explain differences in regulatory capability and effectiveness in both countries.

The following section will review the evidence on the relative position of SOs and EOs in the regulatory ecosystems. Later three sections will discuss the process tracing on the role and impact of SOs, domestic EOs and foreign EOs.

4.2 Liberal regulatory ecosystems

A central precept in liberalisation regimes is the reliance on the delegation of authority to a market regulator that is autonomous from political controls. This organisation preserves the market through a continuous revision of rules and the monitoring of compliance. Market regulators might share authority with other agencies responsible for subjects like equipment standards or protection of competition.

In this section, I describe the relationship between these hierarchies and networks of regulatory ecosystems in Chile and the UK. I introduce the description of the flow of knowledge as captured from the empirical fieldwork research and administrative documentation. Thus, I present the broader set of actors in networks of interactions and an abstraction of the crucial exchanges of expertise.

The analysis of the structure of the ecosystems shows that regulators do engage in extensive knowledge exchange beyond the asset-owners they regulate. This results from regulators' demand for knowledge and a supply of knowledge in the hand of these EOs. However, the supply is not naturally available but historically dependent on regulators creating EOs or nurturing a mission to produce actionable knowledge.

4.2.1 Chile

Chile was the first national economy to embrace liberalisation of the electricity sector at the late stage of the military dictatorship, in the 1980s. Chile revamped its institutional framework in the early 2000s, and later in 2015 within the framework of a presidential system.

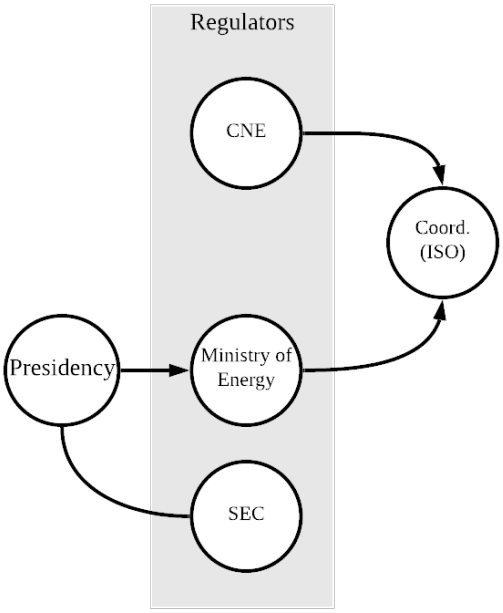
Long before liberalisation, Chile had a technical and quality standards regulator (SEC) and an energy regulatory commission, the Comisión Nacional de Energía (CNE). The 1982 electricity markets laws placed CNE as the regulatory authority of the wholesale market and supply services. It was not until 2010 that the government established a Ministry of Energy. As a result of the 2015 legal reforms, the government incorporated the Coordinador Eléctrico Nacional or national electricity coordinator as an independent public SO.

The new ISO was created by integrating two existing dispatching organisations serving two disconnected grids, one in the north and other in the centre-south. These dispatching organisations were owned, run and staffed by private companies. The legal reforms established the Coordinador as a public entity, with technical autonomy but as a public agency.

Figure 4-2 describes the hierarchical relationship between these regulators. It places SEC, CNE and the Ministry as the official regulators of the sector, sharing responsibilities for market design and monitoring, as well as the deployment of infrastructure regulation and planning. As explained by all interviewees, the SEC has been of little relevance to the subjects of renewable energy expansion as they have mainly focused on the quality of service at the distribution level.

The creation of a Ministry of Energy and later on the creation of a single national SO coincides with the acceleration in the growth of solar and wind energy. Local stakeholders consider the creation of the Ministry as a crucial institutional change to drive effective policy thinking and coordination of policy change. The flagship political process of consultation and analysis occurred around the 2015 process of debates under the title "*Energia 2050"* (Bórquez, 2021; Bustos, Dufrey, & Tapia, 2019).

Figure 4-2. Hierarchy of public authority in Chile

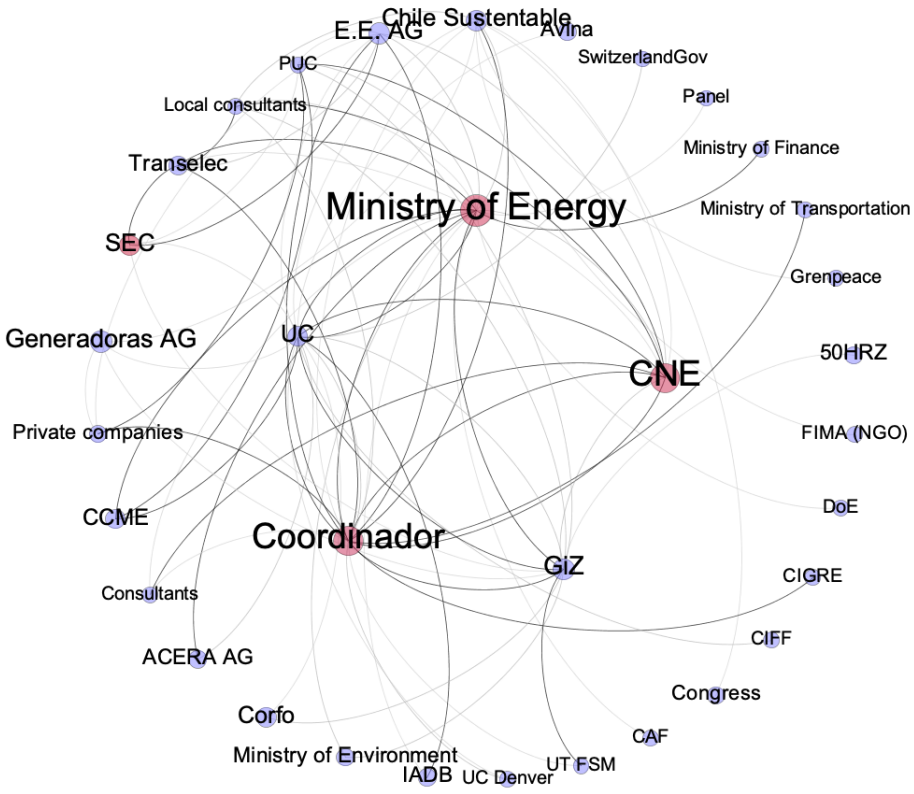


These public actors are embedded in a regulatory ecosystem that, in addition to the target industry, includes universities, consultants, and other stakeholders, like consumer organisations, development banks and private financiers, or environmental organisations. *Figure 4-3* presents the network diagram of all the actors captured during interviews. This dual circle layout presents 34 nodes with the inner circle showing the top-five actors with the highest scores of a combined degree score. Linkages relative transparency is based on the level of importance. An observer can find a visual cue to the relative relevance of certain actors based on the density of lines interconnecting each node.

I recorded the direction of linkages between actors which allowed me to produce network statistics that refer specifically to which actors receive the most attention and which actor provide the most relevant support. I use In-degree, Authority, Out-degree and Hub scores. In-degree and Out-degree simply refer to the number of linkages reported in which expertise is provided towards or from an organisation respectively. The Authority and Hub scores weight degrees iteratively based on the degree levels of the target or source nodes. High Authority denotes nodes targeted by important Hubs, while Hub scores denote targeting the nodes with the most authority in addition

to being targeted by others. Thus, it better reflects the significance of specific actors as the recipient or origin of expertise.

Figure 4-3. Network diagram of knowledge exchange in Chile



Main acronyms

Coordinador: ISO
CNE: National Energy Commission
UC: University of Chile
Generadoras AG: Generation Companies (trade association)
GiZ: German Development Cooperation
PUC: Pontifical University of Chile
EE AG: Electricity Companies (trade association)
ACERA: Chilean Renewable Energy (trade association)
CCME: Scientific Commission on Mitigation and Energy
CIGRE: International Commission on Large Electricity Systems
SEC: Electricity and Fuels Controller

Table 4-1 shows the top five actors according to each score. The In-degree and Authority scores are similar in the first three institutions, the Ministry, the SO, and the market regulator. This ordering contradicts expectations about the centrality of an autonomous regulator with delegated authority. The Ministry is the most targeted, and the SO is more targeted than the market regulator.

As a target of regulation itself, the SO should not be so relevant, especially for non-market participants like environmental advocacy organisations.

The tables for Out-degree and Hub scores show consistencies and minor differences. The main university (UC), the international cooperation program with the longest history (GiZ) and local consultants are very clearly relevant sources of expertise. Local advocacy organisations and trade associations can also claim to be highly regarded as sources of expertise. However, the relevance of these last two types of actors cannot be separated from their role advancing their agenda within the regulatory process.

Table 4-1. Structural position scores in Chile

In-degree score

Acronym	In-degree
Ministry of Energy	16
Coordinador	13
CNE	10
UC	7
Chile Sustentable	5

Authority score

Acronym	Authority
Ministry of Energy	0.56
Coordinador	0.45
CNE	0.43
Generadoras AG	0.22
GiZ	0.20

Out-degree score

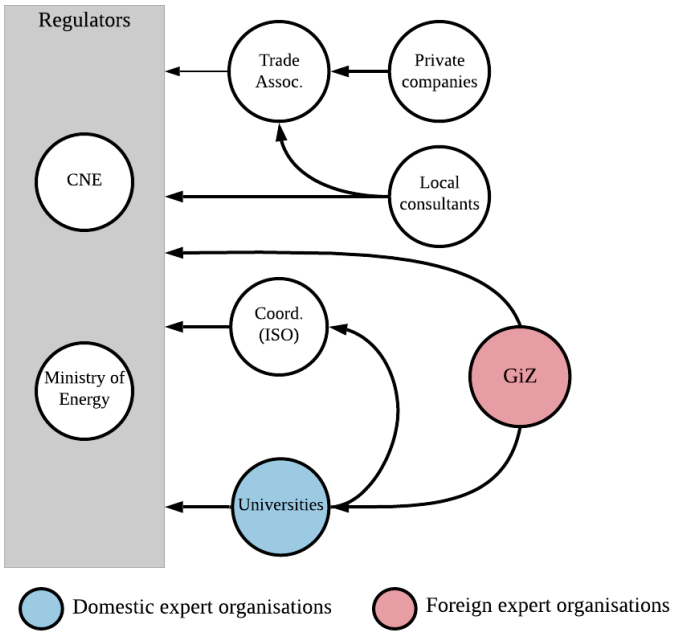
Acronym	Out-degree
UC	12
GiZ	9
PUC	7
Local consultants	6
Chile Sustentable	5

Hub score

Acronym	Hub
UC	0.47
GiZ	0.38
Local consultants	0.33
EE AG	0.30
Chile Sustentable	0.29

I constructed a summary diagram of relations for the exchange of expertise that best represent the flow of knowledge from the technological frontier in the industry towards the regulators, as a summary of the structural and process analysis. *Figure 4-4* already includes the distinction between domestic and foreign EO, and it should be understood as a general approximation to a great variety of expertise exchange.

Figure 4-4. Paths of expertise brokerage in Chile



The central finding in the case of Chile is that there are two alternative paths for the flow of expertise. The first one comprises the private companies which act through trade associations, as well as local consultants that can work for the government, trade associations or advocacy organisations. The second one refers to EOs, which have a direct relation to the Ministry and CNE and also to the ISO. As the previous network diagram showed, there is interaction between these two groups and collaboration existing between universities and trade associations and local consultants, and between international cooperation programs and private companies. However, for the purpose of regulatory making, these are two clearly distinguishable paths.

Chile has a very active set of trade associations which engage with the regulators continuously. In parallel a number of universities and the foreign EOs have established relevant paths of knowledge provision to regulators. GiZ is the outstanding, but no the only, case. This is particularly true for the Ministry of Energy and the ISO. These parallel paths of knowledge exchange define the regulatory ecology, well beyond the formal limitation of regulatory authority.

4.2.2 UK

The UK has built the institutional framework for its energy market for over three decades, with the latest major changes approved in 2013's major overhaul to accelerate decarbonisation. Nested within the UK parliamentary system, the independent regulator Ofgem has remained at the centre of the regulatory process for the electricity sector. It has been the most relevant and, during certain periods, the only decision-maker. During the last decade, the responsibilities over electricity sector policy have moved across ministries, most recently between the Department of Energy and Climate Change (DECC) and the Department of Business, Energy and Industrial Strategy (BEIS). These transitions have underscored the variance in political salience, which peaked during the 2013-2015 period that saw the implementation of new market mechanisms.

For three decades, specific institutions have been created to respond to the different political demands over efficacy, fairness, the exercise of market power and the need to coordinate infrastructure development. The settlement data manager Elexon, for example, was created in 1999 as an off-shot of the National Grid. The Low Carbon Contract Company was created in 2014 as a state-owned company to administer the long-term contract for difference (CfD). More recently, the SO was partially separated from the National Grid in 2019. The National Grid ESO (NG ESO), Elexon, and LCCC are implementing agencies with regulatory roles, either as 'mechanisms administrators' or 'code administrators', entrusted with supervising specific sections of the market rules, or deploying some public function to award and administrate contracts.

The system runs in a self-dispatch principle based on a very liquid market of bilateral contracts, which requires the balancing of supply and demand in the short-term by a central operating agency. In Great Britain, the operation of the system was delegated to a single corporation, the National Grid, which is also the transmission monopoly company over England and Wales.

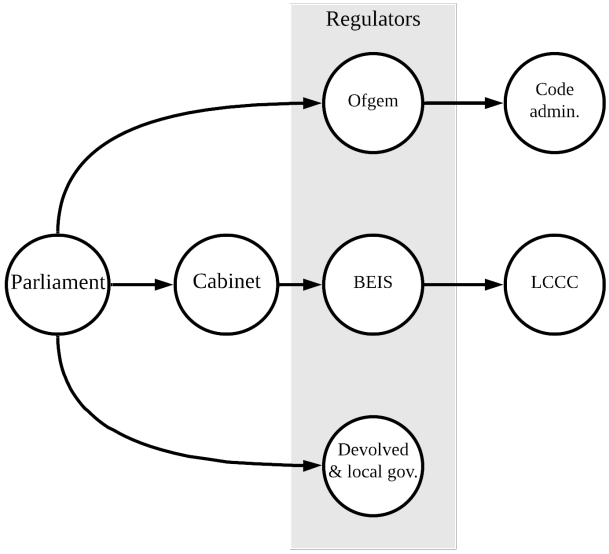
In 2017 Ofgem decided the need for a partial separation to "mitigate any actual or perceived conflicts between National Grid's role as SO and the other roles such as ownership of the

transmission network in England and Wales" (Ofgem, 2017). Formally, it was the National Grid who requested Ofgem for a change in its license, arguing that this arrangement would achieve desired changes at the lowest cost possible for consumers. What today is called the NG ESO is not a public organisation, nor is it fully independent from the grid company, but the license has established significant barriers between the two organisations and has expanded its remit of work.

In addition, in the case of the UK, there are certain relevant regulatory functions mainly concerned with land and industrial planning that have been devolved to local governments. This is relevant given the importance of Scotland as a wind powerhouse and the serious concerns expressed by business about planning restrictions (3B05, 3B07).

Figure 4-5 depicts the relations between these public and private authorities. The figure identifies authority delegated from parliament to Ofgem, the Cabinet and the sector ministry, as well as the devolved and local governments. In addition to these public actors, the regulatory ecosystem considers the existence of code administrators, entities under government or private control that have been mandated by a regulatory license to implement part of the regulatory playbook.

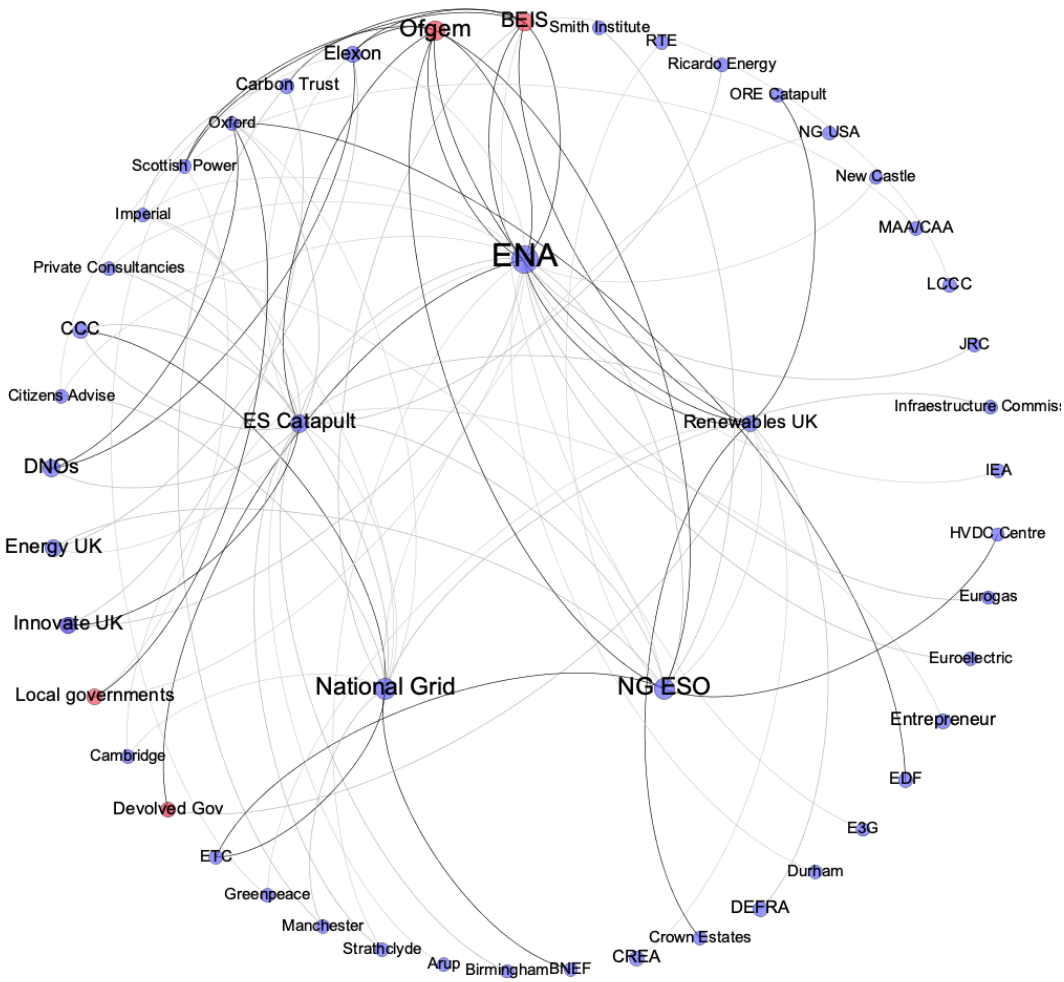
Figure 4-5. Hierarchy of public authority in the UK



These code administrators also have the responsibility of conducting reviews of rules, some of which might be immersed within their own license of operation or more generally within the larger body of regulation established by Ofgem. Elexon, the NG ESO, the Energy Network Associations, are all actors that are not public agencies but have the role of code administrators. They are, in all senses, private regulators, even if Ofgem sanctions any code review.

The fieldwork research and network elicitation present a very rich network of linkages. *Figure 4-6* describes a network of 49 nodes in a dual circle layout. The inner-circle contains the top-five actors on degree scores. This figure allows the identification of the relative density of relations in an ecosystem where BEIS and Ofgem as public. However, their importance lags behind private actors, including the NG ESO and EOs, in addition to the grid company and trade associations.

Figure 4-6. Network diagram of knowledge exchange in the UK



Main acronyms

ENA: Energy Network Association	BEIS: Department of Business, Energy and Industrial Strategy	ETC: Energy Transitions Commission
ES Catapult: Energy Systems Catapult	Ofgem: Office of Gas and Electricity Markets	LCCC: Low Carbon Contract Company
NG ESO: National Grid Energy System Operator	DNO: Distribution Network Operators	CCC: Climate Change Commission

As in the case of Chile, the characteristics of the data collected allowed me to calculate scores for In-degree, Out-degree, Authority and Hub, as means to define some relative position of actors within the larger network. Table *Figure 4-7* present these results for the case of the UK.

Regarding In-degree and Authority scores, ENA, National Grid and National Grid Energy System Operator share the higher position. BEIS also appears as a top-5 in both scores. The Energy Systems (ES) Catapult appears as top-five for the in-degree score, and Ofgem appears as top-five in the Authority score. This result corroborates the idea that code administrators, ENA and NG ESO are crucial targets in the regulatory process. In the next section, I will further discuss the importance of the relation between ENA, the SO, and the National Grid.

Figure 4-7. Structural position scores in the UK

In-degree score

Acronym	In-degree
ENA	17
National Grid	9
NG ESO	9
ES Catapult	8
BEIS	7

Authority score

Acronym	Authority
ENA	0.65
National Grid	0.35
NG ESO	0.34
Ofgem	0.31
BEIS	0.22

Out-degree score

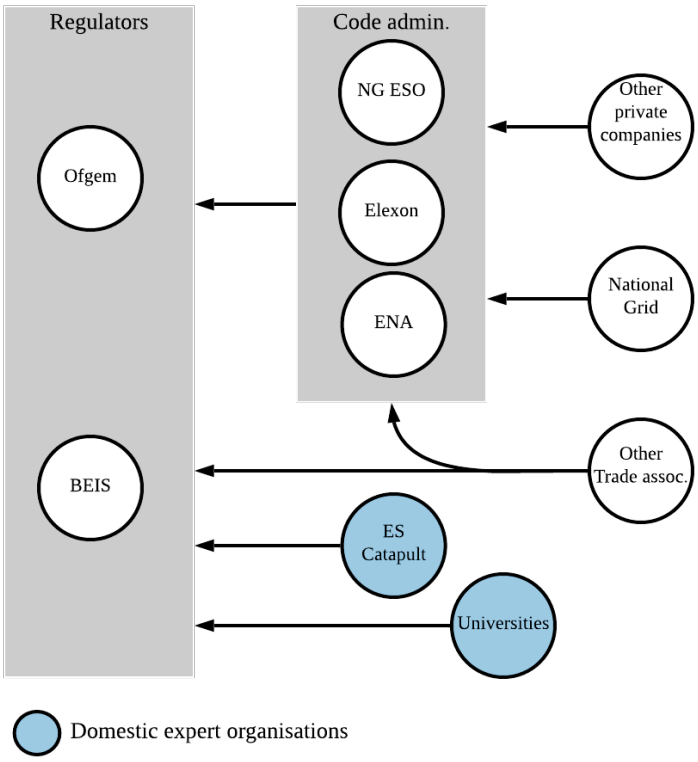
Acronym	Out-degree
ES Catapult	11
Renewables UK	7
Elexon	5
ENA	5
Oxford	5

Hub score

Acronym	Hub
ES Catapult	0.49
Renewables UK	0.33
Private Consultants	0.29
Elexon	0.29
Imperial	0.24

The results on Out-degree and Hub scores are particularly relevant for this research. The results are relatively similar, with ES Catapult, Renewables UK and Universities (Oxford or Imperial) with a place. The settlement data manager Exelon and ENA take places in the top-five. These actors deserve further discussion as code administrators.

Figure 4-8. Paths of expertise brokerage in the UK



As a result of the multi-methods research, I summarise the paths of expertise exchange in a conceptual diagram in *Figure 4-8*. Code administrators play a particular role in bridging expertise. Their mandate is to aggregate knowledge to produce actionable regulatory solutions. The voice and knowledge of National Grid and other private companies are heard primarily through the work of the ENA, but also through the dialogue that Elexon and the SO have with the industry.

While some foreign EO were documented to have a role in the UK, none of them was significant enough to be included in the synthesis. In contrast, two specific EOs were prominent. The first is

the ES Catapult, and the second refers to the group of universities inlcuding Imperial College, University of Oxford, University of Strathclyde and others.

The structure analysis shows that for the case of the UK, there is a very dense network of knowledge intermediation. On the one hand, asset-owners rely on trade associations but also on the Code administrators to provide knowledge for the regulatory process. Code administrators can be a private company as in the case of the NG ESO or Elexon or trade associations. The governance principle is of industrial self-governance and pooling. However, there is a new significant group of alternatives, government created EOs that provide knowledge, including ES Catapult, as well as institutional that pre-date the regulatory need, like Universities. The process tracing analysis will provide evidence to explain this diversity, which depends on regulator's sanctioned contracts, bids and grants to keep them engaged in the regulatory ecosystem. The next three section discuss will discuss this and concrete instances in which these knowledge brokers relations are meaningful.

4.3 Enlisting or appropriating the system operator

The appellative system operator (SO) can be applied to a number of functions to coordinate the industry across geographies and time. The most common functions are scheduling of dispatching, the settlement of transactions in the market, the monitoring of compliance with technical standards, the planning of future infrastructure, and the forecasting of demand and generation to achieve all of the above. But these functions can be distributed amongst different organisations. In Chile all the functions of a system operator were integrated into the Coordinador role after the government appropriated the privately-run dispatching centres. The UK has created a number of actors that play the role of system operator, either enforcing some separation from the National Grid, (NG ESO and Elexon), or establishing new bodies (LCCC). This difference is meaningful to the centrality of SOs in the remaking of the regulatory framework.

Chile approved the laws to create the Coordinador in 2015 (Ley N° 20.936) with the objective to "reduce entry barriers, eliminate economic mismatch between regions and facilitate the integration of renewable energy" (Bachelet, 2015). This required the Coordinador take on roles beyond that of the dispatching centre and to conduct grid planning, project development and new monitoring functions. This is a meaningful change to the industry-led governance systems because it shifts the burden of supervision from market participant denunciation to a public agency. As the government referred in 2015: "Currently, fulfilling the rules and standards is based on the self-management of every coordinated company in the systems and the review of the SIC […] This creates a vicious cycle of breaches from the coordinated companies" (Bachelet, 2015).

Chile's decision to create an independent SO is evidence of the local political decision to use central coordination agency to control undue influence from incumbent asset-owners, but also more centrally coordinated. The UK government's decision to conduct a partial separation of the SO from the National Grid underscores only the first factor, still relying on a highly decentralised governance system.

As stated jointly by BEIS, Ofgem and the National Grid: "Our intention is an electricity SO with a governance structure that mitigates potential or perceived conflicts of interest and is able to adapt further to the changing system in future" (BEIS et al., 2017). A first contrast between the two governments' choices is that the UK decision to introduce only some level of separation of the SO from the Grid Company is a result of the existence of other actors that already had SO-related functions, like the settlement agent Elexon and the Low Carbon Contract Company. The contrast between Chile and the UK is not only between an independent government-controlled SO and a SO integrated to the business of an asset-owner. Rather, it is the contrast between a single independent SO and multiple SOs under the control of different pools of asset owners.

This fragmentation is the result of regulator's concern over asset-owners exerting undue control of market information and the need to assign regulatory implementation authority to non-asset

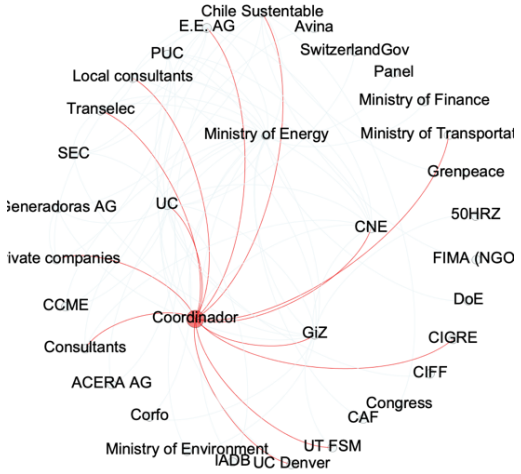
owning actors. We can take Elexon as an example. Elexon was an off-shoot of National Grid from 1999, with high independence from the company created to create autonomy in the data management necessary for settlement activities (3B04). With new roles established by the 2013 legal reforms, Elexon took over additional implementation roles. But the institutional pool was still insufficient, hence the government created the Low Carbon Contract Company to manage the new CfD contracts.

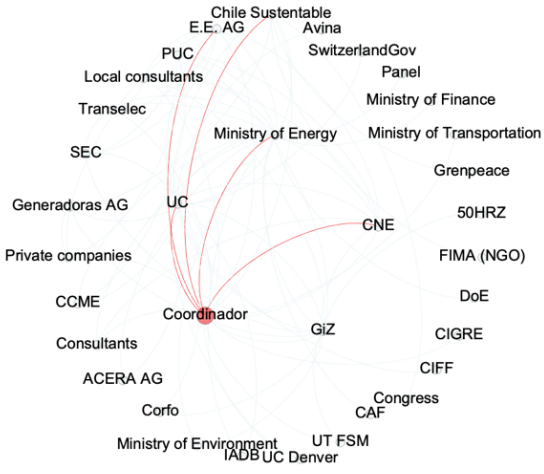
The contrast between a unified independent SO model and that of a fragmented SO model are evident in the structure of relation shown in Figure 4-9. In Chile, the SO benefits from contributions of expertise provided by a number of EO, including universities and consultants. But they provide most of their working results to the Ministry and the Energy Commission. In addition, a limited number of EOs utilise the work results of the SO, as in the case of the Universidad de Chile. In the UK, the National Grid ESO and Elexon benefit from a very limited number of actors, essentially the regulators and the network trade association. But there is a large number of actors that reported benefiting from significant contribution from the National Grid ESO. The main contrast is the significance of centralisation produced by the Coordinator in light of alternative approaches to fragmentation.

Figure 4-9. Broker position of SO in Chile and the UK

Chile

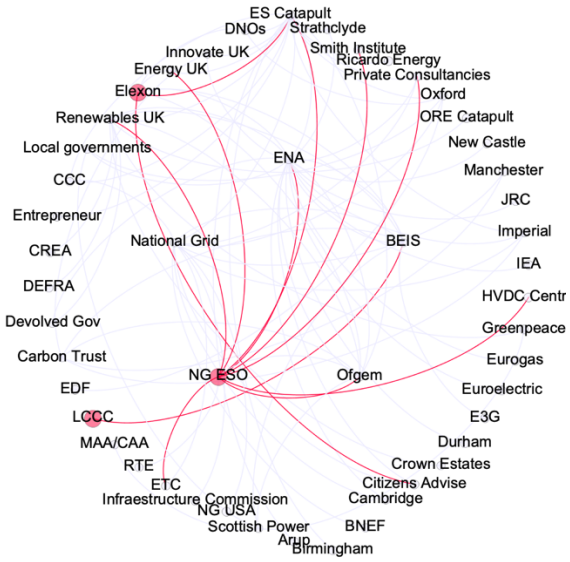
SO Inward SO Outward





United Kingdom

SO Inward



SO Outward

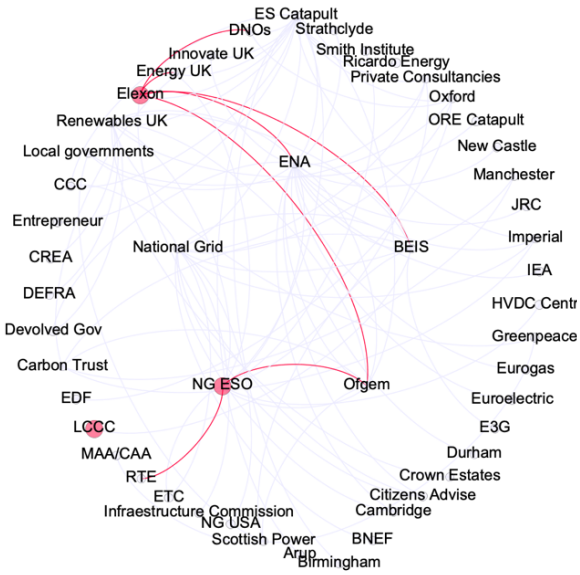


Table 4-2 shows a summary of of which roles have been delegated to different stakeholders. The contrast between the columns is very clear. While multiple roles in market reform, central contracting, planning and monitoring are all developed by a single SO organisation in Chile, in the UK these roles are all distributed between different organisations, the private non-profit ENA, Elexon and National Grid ESO, and the public LCCC.

Central SO organisations, the Coordinador in Chile and National Grid ESO in the UK are pillars in the process of innovation in market reforms. In particular, in 2019-2020, the Coordinador in Chile is leading the process for the creation of ancillary markets. This is a central debate about

who gets paid for the increased flexibility in the system. Incumbent thermal generators have argued the need for new market products that remunerate the additional operating costs of their own plants, by up to 50 per cent of total generation costs in 2030 (Moray PSR, 2018). The generators trade association considers the SO the most central actor to interact within making a case for flexibility payments for conventional thermal generators (4A05).

Table 4-2. SOs and regulatory innovations

Regulatory innovation	Chile	United Kingdom
Market reforms	Coordinador	ENA, NG ESO, Elexon
Central contracting		LCCC
Planning		NG ESO
Monitoring		NG ESO, LCCC, Elexon

The SO role of monitoring is one of the major changes in the system and is one of the areas where scarce knowledge can have the greatest implications. As told by a senior official in the SO, regarding political discussion over the SO role of market monitoring: "The argument is that the economic authority has a hard time to understand the market, at the micro-level, the micro-decisions behind price formation: how it is administered, how the grid is managed. Thus, a competition prosecutor had a blind region that was simply impossible to cover, if not for having an organisation like the operators to help" (4A03).

Apart from leeway in experimenting with future market products, and for monitoring the market, the Chilean SO are entrusted with highly idiosyncratic functions. For example, the SO has the responsibility to supervise the development of grid lines. This is a function that would have been best suited for a field engineering company, not a software-based engineering specialist. But as reported by officials, there seems to be no better alternative for regulators' unwilling to take over

the responsibility themselves (4A05). A public SO can become an institution to hold an increasing number of difficult tasks to fulfil.

Instead, the fragmentation and lack of full unbundling of the SO-like organisations in the UK has resulted in an ecosystem of innovations. Nonetheless, NG-ESO is increasing in importance. The NG-ESO has developed a full program to facilitate the innovation of market products that can be introduced for balancing services under the name "Pathfinders", in the form of an open dialogue with an entrepreneurial business willing to propose new business solutions for problems of stability, voltage control and other foreseen future problems. As part of this process, the SO can experiment with companies, for example, on different energy storage technologies that currently do not have a place in existing remunerated markets (3B08). This innovation space feeds into a larger workstream of market planning named the Network Options Assessment which the NG-ESO delivers to Ofgem.

The NG-ESO is now entrusted with planning mandates beyond those strictly necessary for the operation of the system in the short and mid-terms. Under its new license, it has been entrusted to develop the Future Energy Scenarios (FES). These are stakeholder-based scenario exercises to convey potential future development pathways in the sector.

The creation of the FES and its hosting at the National Grid ESO is a central example to the argument of this thesis. The FES responds to the government's goals like the net-zero emission target but attempt to develop alternative views of possible paths to achieve them (National Grid ESO, 2020). It also shows the implications of having a private industry-run planning process. The industry, the government and most stakeholders consider the FES as one more input to their vision of the future rather than an authoritative report. This is a stark contrast to the work developed in Chile by the Coordinador and the Ministry, whose long-term outlooks are the definitive reference to the industry.

The parent company, National Grid, considers these scenarios as one more input from the industry (3B09,3B10). At BEIS, the results of FES are considered a relevant input, but not a policy roadmap (3A02). But still, other stakeholders consider this the closest to a public set of scenarios (3B06). In making the FES, the ESO intends to capture opinions and evidence from stakeholders to integrate plausible avenues for future development. It is central that their responsibility to adopt this role is established in their license, that they are remunerated and evaluated for their effectiveness in gathering stakeholders' views and developing a whole-system perspective. Absent the exercise of the FES conducted by the National Grid ESO on behalf of the regulated industry, the only other authoritative source of intelligence about the future would be the Climate Change Commission, whose working calendar and agenda of priorities are not necessarily the same as those of the electricity industry.

In Chile, there is no confusion about the central role that the SO has in developing scenarios about the future development of the industry, specifically regarding the transmission system. These tend to be considered an authoritative voice. Hence, all advocacy organisations, from trade associations to environmental groups, dialogue with the work published by the Coordinador. However, the Ministry has maintained the role of planning that is equivalent to the FES in the UK, to be able to incorporate debates about sectors beyond the electricity industry more effectively through the development of Long-Term Energy Planning (PELP in Spanish) (4A01).

As an example, during 2019 the Coordinador interacted with trade associations on studies about new market products for the remuneration of flexibility services for conventional thermal power plants. This has been a critical request from incumbent generators that see their revenue stream wind down due to the growth of renewable energy. Simultaneously, the SO has become an essential factor in discussions of the coal phase-out. Previous policy discussions were based on scenario analysis provided by the University of Chile or other EOs, for example, through the Energia 2050 process. But in 2019, in discussions with advocacy organisations and the industry,

the SO authored scenarios to assess the technical and economic viability of phase-out which were used for the government-industry agreement to replace all coal power generation no later than 2040. The SO collaborated with Chile Sustentable to produce its own alternative scenarios showing that phase-out could be achieved faster.

4.4 Creating, enlisting and contracting domestic expert organisations

I have previously mentioned the arguments of Wolak (2014) and Joskow (2014) on the need for external sources of expertise to monitor the market and enable regulators to contract specialist experience. Expert Organisations (EO) play that role. This can happen in the form of existing knowledge-based institutions being enlisted to participate in regulatory processes; this is, what occurs when regulators "call for evidence". It also happens through consultancy contracts. In general, the assumption is that these EOs are already in existence when regulators need them. But from a historical perspective, it is important to acknowledge that, from their inception, some of these EOs are the product of regulatory choices.

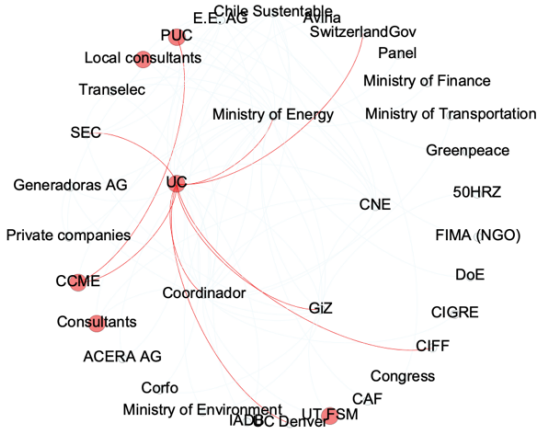
The findings from the research showed that the two liberal markets have well-developed frameworks for contracting EOs for specific regulatory products. However, EOs have proven to be important beyond contracts; they have been critical in guiding the future of the electricity industry when major policy debates are held. In Chile, this evident in the "Energy 2050" process, and in the UK through the work of the Climate Change Commission (CCC).

Figure 4-10 provides the network graphs that depict well interconnected domestic EOs. In the case of Chile, the University of Chile is particularly relevant as it collaborated with other EO, but provides significant knowledge to the regulators, the SO and numerous stakeholders, including asset-owners. These patterns are very similar in the case of the UK, especially for ES Catapult, CCC, Carbon Trust and Universities. These network graphs shows that the EO ecosystem in both countries is similar.

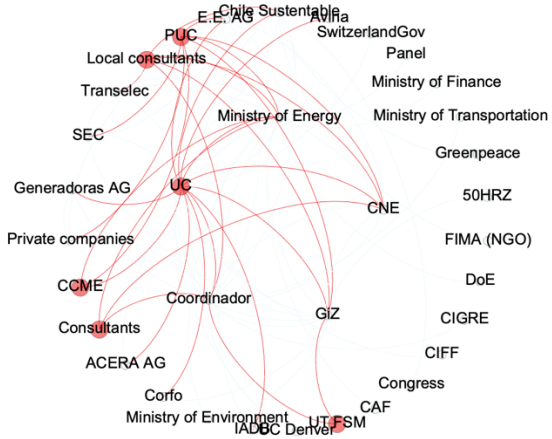
Figure 4-10. Broker position of domestic EOs in Chile and the UK

Chile

Inward

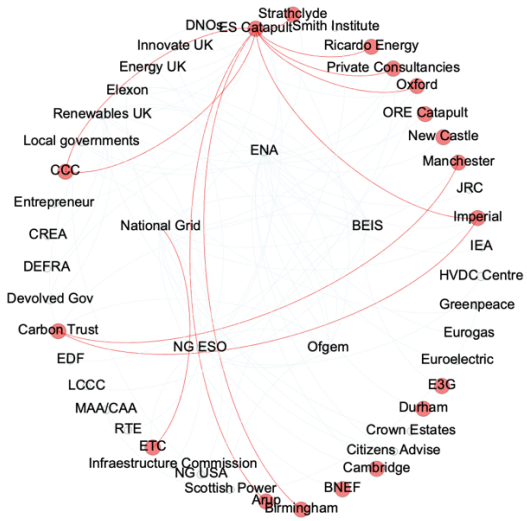


Outward

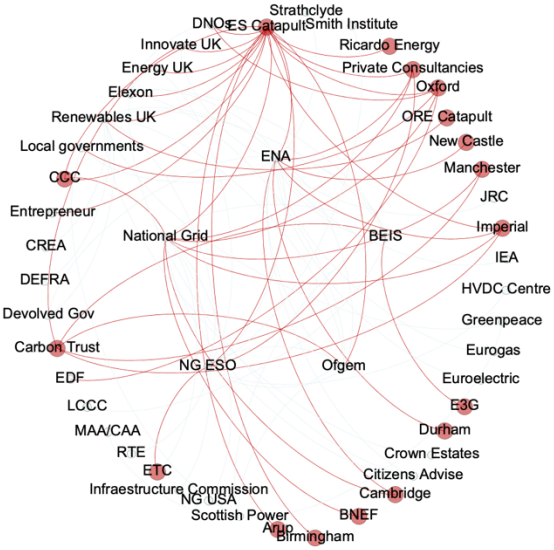


United Kingdom

Inward



Outward



The participation of domestic EOs in Chile and the UK is very different due to the mechanisms by which regulators engage with EOs. Table 4-3 presents a summary of instances of participation of EOs in both countries as documented in the fieldwork. Universities are important in both cases. However, the basis for their participation is very different. In the case of Chile, their participation is based on specific consultancy contracts or open expert consultations, and in particular the

Energia 2050. In the case of the UK, their participation also occurs in open expert consultations, but primarily through public and private funded institutionalised mechanisms for innovation funding like UK Innovation, and those funded by regulated tariffs in the electricity systems, the Electricity Network Innovation Allowance (NIA) and the Network Innovation Competition (NIC).

Table 4-3. Domestic EOs and regulatory innovations

Regulatory innovation	Chile	United Kingdom
Market reforms	Universities, Local consultants	ES Catapult
Central contracting	-	The Carbon Trust
Planning	UC (Energia 2050)	CCC, ES Catapult, Universities
Monitoring		ES Catapult, Universities

In Chile, almost all interviewees agreed that the Energia 2050 was the critical mechanism to shape the current energy landscape. The process was launched by a newly created Ministry of Energy to hold a broad discussion over reforms to the industry. Previous ideas have already been discussed but not passed in Congress. This mechanism encompassed debates beyond market design, including land and social conflict management, central infrastructure planning, and the restructuring of the institutional landscape. The process served to create consensus about the creation of the independent public SO and over the feasibility of large-scale expansion of renewable energy in the country (Bórquez, 2021; Pacheco, 2019).

The debates on renewable energy were conducted at the University of Chile Energy Research Centre (UC) using their energy modelling capabilities. Researchers from UC served as technical clerks, and participants tested a different hypothesis about the development of the system. Their work resulted, for example, in the realisation that the operational conditions stated by some

incumbent coal generators had resulted in inappropriate market behaviour. This misbehaviour would be prosecuted by the authorities later on (4C04).

The participation of the UC in the Energia 2050 process is critical evidence of regulators bridging knowledge from the frontier. The suite of models of the UC was originally developed years before under the auspices of one of the largest coal-power generators, as part of the operation of one of the two electricity systems. They supported one of the predecessors of the SO and, more recently, they also work for the ISO for long-term planning (4C02, 4A05). The tools have been utilised by advocacy organisations like Chile Sustentable, and expert mechanisms like the Science Committee for Mitigation and Energy (CCME) (4C02, 4C04). This explains why UC is so clearly central in Figure 4-10, they benefit from the exchange with a number of other stakeholders, but a very large number of actors have depended on their work.

Since 2015, Chile's regulators have built further sources of expertise and avoided establishing a unique source of expertise or a primus inter pares amongst EOs. The Ministry of Energy created an internal planning unit. This unit has been staffed by a former member of UC and has started with the UC models and experience, aiming to extend into other planning objectives (4A01). Experts in multiple universities and continue developing their own regulatory reforms proposals with the help of local and international consultancies, from locations like Brazil (4A04, AC03). It is noteworthy that during the Energía 2050 process, there were discussions concerning the creation of a public Energy Institute as a central hub for information, analysis and evaluation of policy (4B02). The proposal was discarded to avoid reducing the political power and significance of the still young Ministry of Energy (Bustos et al., 2019, p. 363).

The fieldwork research and administrative record review in the UK showed a very different environment of expertise exchange. Interviewees referred to two forms of EO participation in the regulatory process. The first is the formal consultations and call for evidence conducted by Ofgem, BEIS or key code administrators such as the Energy Network Association. The second is the

existence of the competitive funding allocation Network Innovation Competition (NIC) and Network Innovation Allowance (NIA).

I found that the most common framework for participating in regulatory innovations was the use of UK Innovation, NIC and NIA funding. This not only means that EOs enjoy some form of public funding (from the central treasury or regulated tariffs), but that funding is spent within a curated environment where regulators set the basic rules for collaboration between the target industries and the EOs (3C04, 3B06). An accessible example is the Local Energy Oxford (LEO) project conducted with local distribution network SSEN, the University of Oxford, local authorities in a number of private companies across generation, retail, flexibility services and storage. The results of this project will feed into asset-owners business models and strategy, and through them into potential regulatory innovations.

Industrial stakeholders reported collaborating with a number of universities that have strong teams working in electrical engineering and similar fields, including Imperial College, the University of Manchester and the University of Strathclyde. Regulated funding mechanisms have allowed the consortium of industry actors and EOs to present regulatory innovation to Ofgem, or market products to the SO, and on occasions also policy-relevant findings to BEIS or another relevant ministry.

In complement to the rich environment of programs to support market innovations, two actors have a particularly important role in the subject of planning: The Climate Change Commission (CCC) and the Energy Systems (ES) Catapult.

The CCC is an independent public body responsible for advising the government over climate change and climate action, including the establishment of Carbon Budgets (Averchenkova, Fankhauser, & Finnegan, 2018). Their work is based on the capabilities distributed amongst many EO, universities and consultancies. As discussed with several interviewees, the CCC's work on scenarios remains the closes authoritative scenario of the future for the energy industry, as their

work is used to establish an official carbon budget. The relevance of the CCC in the electricity sector is the result of lack of leadership by regulators, as described by a member of the National Grid: "Nobody wants to make that tough call and coordinate and we don't have any other than the CCC [….], we don't have any [other] organisations within the UK that's really got that expertise" (3B09).

The ES Catapult is a government-sponsored agency, based in Birmingham, that acts as a facilitator of innovation in the field of integrative technologies for the energy industry, as part of a broader family of Catapult centres. Another relevant centre is the Offshore Renewable Energy (ORE) Catapult in Glasgow. The Catapult units collaborate with other EOs relevant to specific subject areas, ES Catapult has very strong ties to a handful of universities and local consultancies, while the ORE Catapult is tightly linked to The Carbon Trust, an EO responsible for helping the UK government pick offshore wind as a winner in its industrial policy. Institutions like ES Catapult arrive in a crowded environment, and even their own official recognises that for some of their own work, including on planning and modelling, they compete with other EOs (3C01, 3C02). The CCC, ES Catapult, The Carbon Trust all share a commonality they were originally established by the government, even if incorporated with different missions. Interestingly, the CCC has no particular mandate toward the energy governance system, but to a broader ecosystem of climate policymaking. These actors truly function as hubs or brokers of knowledge in the UK, as part of a well-established mandate to function as such.

These actors are relevant as they push forward specific regulatory agenda. For instance, in the arguments presented by the National Grid regarding the separation of the ESO, they quote the work of Imperial College and the Carbon Trust for the National Infrastructure on the economic benefits of taking a "whole systems approach" (National Grid, 2017). Different interviewees referred to the work of the ES Catapult and its predecessor the IET to defend the need for a "system architect" which would be able to take a whole system perspective (IET, 2014; IET &

Energy Systems Catapult, 2016). This debate occurred between 2014 and 2016, as major decision on the new regulatory framework had already been decided, for example, through the Contract for Difference framework, but issues like curtailment and balancing costs were rapidly increasing in prominence. Therefore, this work ignited regulators' discussions on issues like the separation of the SO, the revision to the mandates of the SO and other code administrators, and the revision of the multiple grid codes.

EOs, like the University of Chile and ES Catapult, provide relevant inputs at crucial decisions points. They are requested to do so by regulators. They mostly help shape the political agenda, opening up discussions based on particular areas of expertise like system planning to prove the opportunities of regulatory change, and proposing specific avenues for regulatory innovation. However, unlike SOs, they do no hold delegated regulatory power.

4.5 The absence of foreign expert organisations

Foreign EOs are relevant in a different context because they provide knowledge of the technological frontier and regulatory solutions in other jurisdictions. The objective of foreign EOs is usually to achieve this translation of knowledge. Foreign EOs include private consultancies whose main experience is in another jurisdiction, The Carbon Trust working in Chile or Mexico, for example, would be a foreign EOs in those countries. Other foreign EO include public technical cooperation programs whose intention is to transfer valuable knowledge across jurisdictions as part of bilateral or multilateral platforms. Finally, multilateral actors dedicated to providing expertise can also be considered EOs; this might include the International Energy Agency, or the International Renewable Agency, or specific European institutions.

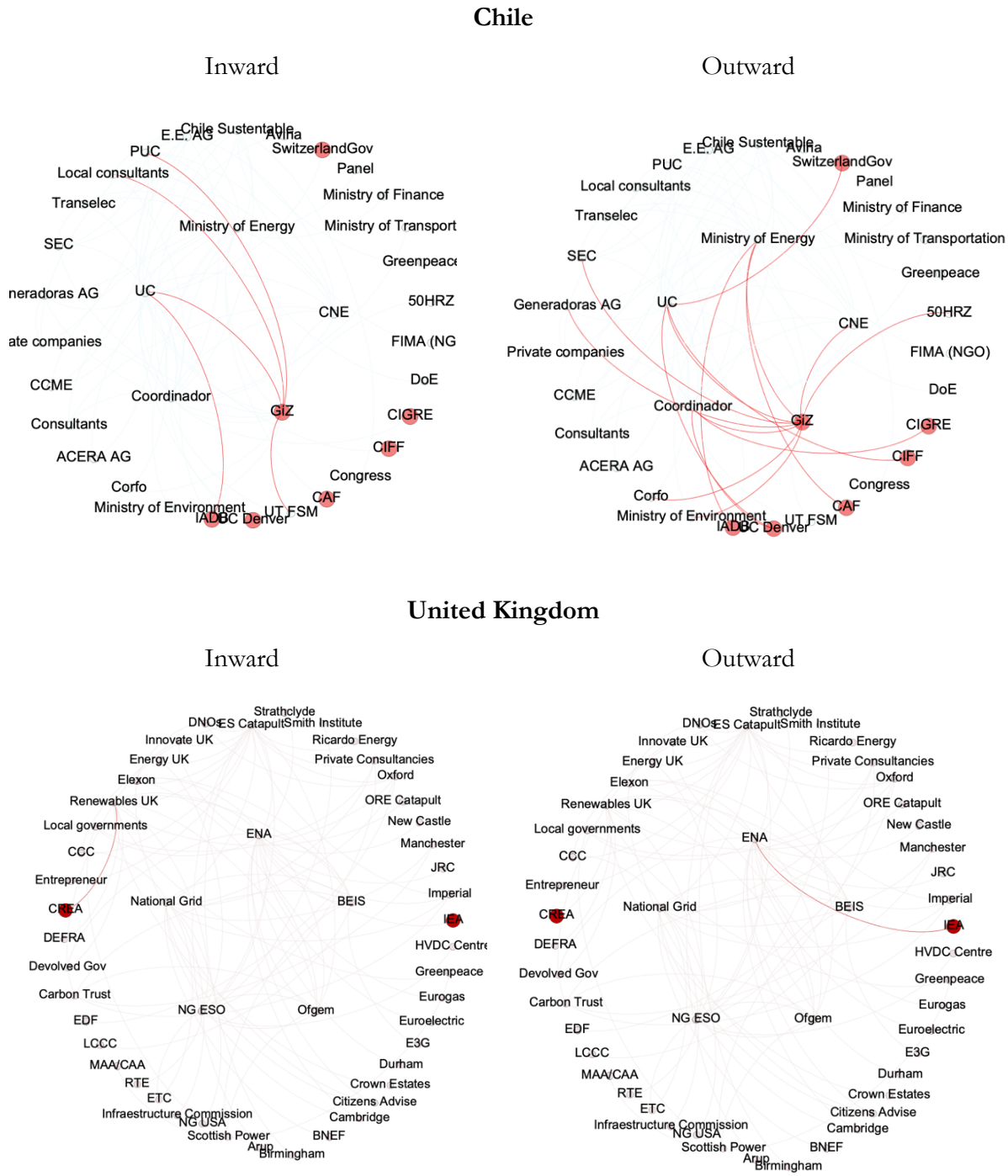
The expectation of this research was that foreign EO would also be important and that it would be possible to find clear traces of evidence of their crucial role in developing market reforms useful for renewable energy expansion. Given significant variation across the globe, there are rich opportunities for diffusion of institutional innovations. EOs can be those means of diffusion of

experiences and transmission of knowledge. In particular, in the case of the UK, I expected European-level EOs to appear predominantly in the interviews.

The empirical findings were inconsistent with this expectation in the UK and very weak in Chile. In particular, in the UK, the administrative records and interviews did not allow me to document the clear presence of foreign EOs. In Chile, foreign EO presence has been important but limited in number, and those few EOs have tended to work with local EOs rather than with the regulators themselves so that nesting within local EOs is important. *Figure 4-11* represent these findings through the linkages between foreign EOs and local actors. For Chile, the diagram shows that the most relevant foreign EO, the German GiZ, provides support to a number of actors, both regulators and trade associations. GiZ works with local EOs, mainly universities and local consultants. Other foreign EOs are less embedded, but they also tend to work through local EOs, and especially the University of Chile, and have targeted mainly the Ministry of Energy but no other regulators. In the UK, there were no relevant relations reported. Even the interaction with the International Energy Agency and the ENA was not considered to be significant.

A large number of key actors in government, universities, trade associations and advocacy organisations identified GiZ as the crucial foreign actor. They have a long history in the country, and there were several examples of their significance. As summarised in Table 4-4 GiZ has worked in market reform for the expansion of renewable energy. GiZ supported the introduction of forecasting renewable generation to modify dispatching schedules. This was a was a crucial step reforming the market. GiZ has worked in the country since 2004, so the impact could not be easily documented. However, they did contribute to funding and assisting UC in the development of models.

Figure 4-11. Broker position of foreign EOs in Chile and the UK



Other actors are less visible. For example, the Children's Investment Fund Foundation (CIFF) funded and supported the Mitigation Action Plans and Scenarios (MAPS) project which enabled Chile to show its commitment to the Paris Climate Conference in 2015. In doing so, CIFF co-founded the development of the models that would be used in Energia 2050.

Table 4-4. Foreign expert organisations and regulatory innovations

Regulatory innovation	Chile	United Kingdom
Market reforms	GiZ, UC Denver	-
Central contracting	CIGRE	-
Planning	GiZ, CIFF	-
Monitoring	-	-

Source: Author.

The limited instances of foreign expertise are very strong evidence against the knowledge broker hypothesis. There are three conditions that help explain their absence. Firstly, these jurisdictions are relatively advanced in market design, so that the potential learning is overshadowed by the amount of support they provide in Europe or Latin America. In both cases, a number of interviewees express their role in providing support to other jurisdictions rather than receiving.

A second explanatory condition is that industrial actors are the knowledge brokers between jurisdictions. Large players in the UK and Chilean markets, like Iberdrola, EDF and ENEL are leading worldwide in the deployment of solar and wind energy, and therefore are well-positioned to broker expertise through their own international networks.

A third explanation is that no tacit knowledge has been codified to the extent that local regulators can already access it without the need of a broker. Chile offered a very clear example of this circumstance, as officials in the Ministry of Energy explained that their studies on distributed or embedded solar energy generation were developed based on tools from the US National Renewable Energy Lab (NREL), which were open-source and available on the internet (4B02).

4.6 Conclusions: regulators strive for redundancy

The purpose of this chapter was to test the hypothesis that greater access to SOs and EOs enables regulators to develop more innovative and effective regulatory solutions by increasing the provision of knowledge. The design entailed controlling for the institutional structure of the

industry. Chile and the UK are both fully liberalised systems in the hands of private interests. This chapter provided evidence to the fact that SOs and EOs matter, often in ways that are not fully accounted for in the standard literature on market design in the electricity industry. I show that regulators need to continuously redesign markets, plan the system, and supervise it. SOs and EOs play important roles as alternatives sources of competence from those of the private industry.

In a context of private ownership of the industry, trade associations are the most relevant source of knowledge. In the UK, these trade associations are entrusted with the role of quasi-regulators, making decisions, setting agenda and developing analyses. In Chile, trade associations had roles encompassing knowledge aggregation and preparation for regulation, but never acquired the regulatory roles of the code administrators in the UK. The SO and E'Os positions as brokers is important because industry-led governance through trade associations like ENA in the UK are not sufficient to guarantee the regulators an appropriate level of access to expertise and the knowledge frontier.

Stakeholders in the UK electricity market remained suspicious of the National Grid's role in planning and evaluating alternatives for future infrastructure development on behalf of the regulators. The National Grid is a player in the building and operation of interconnectors with continental Europe and is invested in the gas industry. Thus, stakeholders were concerned other technological or operational alternatives will be bypassed to benefit these business lines. In Chile, the lack of investment in transmission benefited incumbent generators, but the government had almost no capacity to plan and coordinate the investment into new transmission infrastructure.

The chapter told a story of two countries have adopted different paths for managing the problem of incumbents' strategic use of the competencies on engineering and economic planning. In Chile, the government-industry consensus favoured the creation of an independent public SO that would absorb the two dispatching centres controlled by the incumbent asset-owners. In the UK, the government-industry consensus preferred a light touch, only the functional separation of the SO

from the rest of the National Grid Corporation, through a change in the license of the National Grid.

The evidence is overwhelming that some greater access to the SO is better; this is what independence and separation mean to a regulator. Within Chile, interviewees with government identified the SO as the critical partner to acquire specialised knowledge at the point, but the SO also strengthen the work of advocacy organisations that contribute to the regulatory process. In the UK, the role of the National Grid ESO is growing in importance and tools, and the widespread opinion –even by members of National Grid– that the ESO office would be turned into a public agency speaks of a growing understanding of the need to assign further regulatory roles to the SO, something that cannot happen without full independence.

As paragons of liberal governance, neither the UK nor Chile had a tradition for conducting central planning of the system. The industry developed infrastructure plans reviewed by Ofgem in London or CNE in Santiago. But now government sponsor the formulation of scenarios and plans for the long-term development of the industry through public agencies, as in Chile (Ministry and Coordinador), or through a quasi-public agency as in the UK (CCC and NG ESO).

Beyond the SO, the ecosystem of EOs was critical. In the UK there is a hybrid environment of institutions created by the government with specific missions like the CCC, ES Catapult, and Carbon Trust, and existing actors like universities whose participation in the regulatory process derives from regulators decision to allocate tariff revenue for their involvement through NIC and NIA competitive mechanisms. In Chile, there are no EOs created by the government that play the brokers role, as underscored by the abandoned project to establish an Energy Institute. Rather, regulators prefer, participatory mechanisms like parliamentary commissions and Energia 2050 or consultancy contracts that serve as the basis for knowledge access.

A network with sufficient redundant paths will empower regulators and reduce the potential power of the incumbent industry. The expectation from regulators and EOs is for there to be redundancy

in expertise, to increase the flexibility in the access to information. Ultimately, the relative importance of a single broker diminishes. The UK has achieved this state of affairs through generous public and consumer funding, and Chile is moving in the same direction. However, there is still the problem of central coordination, which the UK has not yet achieved.

The finding of growing redundancy is an extension of the broker hypothesis. The higher the redundancy in EOs or even SO-like organisations means decreased importance of any particular intermediary. If many EOs can provide knowledge, then no one is a broker. This is the ideal of a marketplace of expertise where regulators are able to gather knowledge from multiple indistinguishable sources. The scarcity of knowledge is historically contingent. The success in regulatory innovation leads to the codification and diffusion of knowledge, and regulators acquire capacities to perform the work or to contract the work within a larger market of experts. Nonetheless, the next phases of renewable energy expansion with new challenges of system integration once again entail the use of tacit knowledge. The two cases, bur specially the UK, provide evidence that regulators have agency over the construction of this robust environment of expertise through building a funding and engagement environment for these non-asset owning institutions, like Universities. But the importance of redundancy in expertise speaks to the political relevance of brokers. Ultimately, no regulator should prefer to dependent on a single or a few sources of knowledge, for these would be prone to slack and capture and the risk of consolidating power outside the office of the public regulator.

5 Knowledge brokers in state-owned industries

This chapter compares two large industrialised economies, China and Mexico, where the electricity industry is dominated by one or several state-owned companies. The two countries have progressively adopted several features of competitive liberalisation, but competition in markets takes place with the predominant participation of state-owned companies. In this context, market regulation is the expanding form of government intervention, in opposition to central government direct investment management.

Coincidently, both China and Mexico enacted their first renewable energy promotion laws in 2009 and later adopted renewable energy expansion targets as a tool for guiding policy and industrial development in 2012. In 2020, China announced a carbon neutrality target by 2060, which is expected to entail near full decarbonisation of the electricity industry by 2050 (He, 2020). Mexico has yet to revise its domestic long-term policy but maintains a mid-term target for 35 per cent clean energy by 2024. Despite the multiple differences that might set these countries apart, both shared a complex domestic outlook for the expansion of renewable energy in the2010s. Economic interests from incumbent asset-owners with a fossil fuel power generation base, from coal in China and from natural gas in Mexico, represent a force that undermined the rapid deployment of wind and solar energy.

Renewable energy integration has faced multiple forms of regulatory restriction, including limitations to interconnection or restrictions to operation whenever they displaced incumbent fuels source from dispatching schedules. In China, this occurred in the form of very high levels of

curtailment, and in Mexico through limitations to interconnection permits. The effective deployment of renewable energy required regulation to overcome these limitations.

This chapter provides evidence that knowledge brokerage is crucial to overcome potential barriers established by incumbent state asset owners. However, no specific type of knowledge brokerage is indispensable for effective regulatory innovation, not even the Independent System Operator. The comparison shows the rising importance of knowledge brokers in state dominated regimes. State ownership does not entrail effective control nor access to knowledge by the regulators. In fact, it might represent less relative power in the hands of regulators as they work towards steering organisations with a similar political and institutional status. The presence of knowledge brokers redistributes the gravity of industrial governance towards central government authorities, shifting the relative power of regulators independently from the relative institutional status of the state-owned companies.

System operators (SOs) are state-owned, either directly under the control of the national government or indirectly as part of state-owned grid companies. In either case they are increasingly salient in defining the specific character of new liberal institutions. However, the greater the independence from the incumbent grid companies, the more they hold a role of rule makers shaping the structure of the markets for which they are meant to serve as a back office. Expert organisations (EOs) are, to a large extent, defined by the historical legacy of state-ownership. Thus, some EOs are directly under the control of the same regulators, while other have longstanding relationship with incumbent state-owned companies. EOs might not have autonomy or independence from the state, but they still represent an alternative to the incumbent asset-owned interests. They can provide crucial knowledge for regulation, for example, by providing software solutions to implement regulatory precepts for efficient dispatching of renewable energy.

Knowledge brokers help regulators retake authority over subjects that had previously been delegated to state owned companies, including planning and the definition of operative rules. This

is particularly relevant for regimes where planning has remained nominally an important tool of governance, as in China and to a lesser extent in Mexico. Regulators have finally taken on the role of planning with the support of EOs or SOs. This transformation enables regulators to provide a policy imprint for future investment planning, rather than depending on incumbent industry preferences to inform the plausible paths of decarbonisation.

Chapter 3 already provided a discussion of the comparative performance and structure of interests between the two countries. It is crucial two address to puzzles: one is the favourable turnaround from Mexico between 2017 and 2019, and the second is the very rapid reduction of curtailment in China during the same period. This chapter comprises six section to answer these puzzles. The first section provides a succinct summary of the theoretical framework's observable implications for state-run regimes. The second section introduces historical and network analysis to describe the structure of the regulatory ecosystem. After providing this institutional structure analysis, the following three sections are dedicated to the process analysis of the participation of SOs, domestic EOs, and foreign EOs. The chapter concludes with a discussion of the interacting effects between SOs and EOs.

5.1 The theoretical framework for regulatory governance in state-dominated regimes

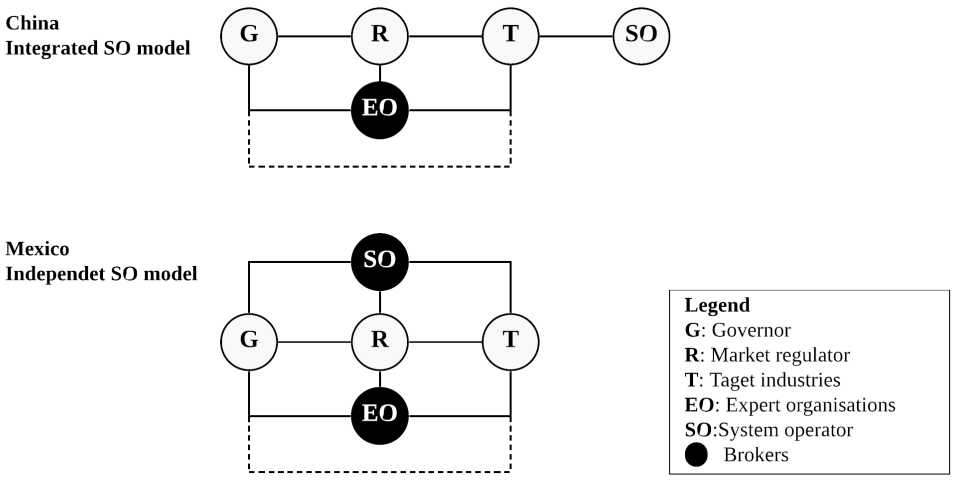
The liberalisation literature has argued that political failures associated with state-ownership result in companies circumventing the discipline that market competition provides. Much of the research into the political economy of state-ownership portrays developing economies as the frontier of restructuring. These studies tend to focus on state-ownership as the defining condition to explain under-performance, as state-owned companies don't have appropriate performance incentives or can sway regulation towards their preference. But many of these ideas developed in light of state-owned company self-governance systems.

In regimes with market competition dominated by state-owned enterprises, regulators set rules and monitor compliance for all market participants. However, political leaders have additional means to control state-owned companies to adopt policy objectives and shape market behaviour. This does not mean that regulators have access to their unique knowledge unencumbered. The relationship between regulators and state-owned industries, their autonomy, depends on idiosyncratic institutional evolution.

Regulators in Mexico and China have introduced multiple features from liberal models, but their electricity systems are still dominated by state owned companies under the control of the national governments. One specific difference between the two jurisdictions is the presence of a unified system operator that is independent from asset-owning companies. Mexico established this independent SO, but China has only recently started a process to diversify ownership of SOs from the two largest grid companies to a broader number of asset owners.

Figure 5-1 presents the contrast between a model of indirect governance as would occur under an integrated SO model or an independent SO model. The two models portray the distinction between a situation with a delegated regulator having authority over a target industry that encompasses the functions of the system operator, and a regulator having direct and differentiated authority over the target industry and the system operator as a stand-alone target of regulation.

Figure 5-1. Models of indirect governance in state dominated electricity systems



Under an industrial structure with dominant state-owned companies, a central authority delegates or shares authority with a regulatory agency but has parallel means to remain involved in the control of state-owned regulated companies. The governor control occurs through the appointment of the CEO, and through state-asset holding governing bodies. Direct appointment and corporate control coexist with the regulatory logic and tools of regulatory governance. State-owned industries act within the regulatory framework but maintain an advantageous access to regulators.

The significance of state-owned companies access to regulators is two-fold. Firstly, it might compound the challenge of overcoming opposition to decarbonisation. If the interest of the company depends on a particular technological platform or fuel, it is possible to speak of an 'incumbent fuel' that conflicts with the expansion of clean energy and in particular wind and solar energy. Secondly, it might have effects on the access to knowledge by regulators. As long as state-owned companies receive a mandate to fulfil public objectives, the conflicts between regulators and the state-owned companies will remain conflated as lack of coherence, rather than conflict of interests. This obscures the implications of the knowledge asymmetry between the companies and the regulators.

The literature in political science has focused on state-owned companies as asset-owning incumbents that represent the most significant challenge to decarbonisation (Prag, Röttgers, & Scherrer, 2018; Urpelainen & Liu, 2018). This follows a long-held research line which depicts state-owned companies as opposing or capturing processes of liberalisation (Foster & Rana, 2020; D. Victor & Heller, 2008). A static understanding might not be the most appropriate theoretical framework. In the 2000s Mexico's CFE was described through its opposition to the expansion of private-owned natural gas power plants (Carreón-Rodríguez et al., 2006). A decade later, the same company became one of the largest consumers and traders of natural gas in all of North America. In China, most wind and solar energy deployment is conducted by state-owned companies which

support the expansion of the grid that facilitates further integration of renewable energy (Zhu et al., 2019).

Regulators should be able to reshape market institutions in order to lead incumbent asset owners to contribute to the expansion of renewable energy. Beyond achieving this feat, even if incumbents engage in investments for renewable energy, regulators will still need to respond to incumbent asset owners strategic use of knowledge. A grid company might favour investment to integrate more renewable energy or a generation company might prefer generous subsidies or guaranteed feed-in rates.

The theoretical framework of this research proposes that system operators (SO) and expert organisations (EOs), as non-asset owning actors, can provide regulators with knowledge and expertise that is distinct from that which asset-owning actors would be interested to provide to regulators. The presence of brokers is meaningful because it increases the overall capacity of the regulatory ecology. The following section provides the historical and network analysis on the constitution of that regulatory ecology.

5.2 State-dominated regulatory ecosystems

In this section, I describe regulatory ecosystems in China and Mexico. I represent regulatory control and the pathways that describe knowledge provision to regulators. Between 2013 and 2019, Mexico and China experienced several structural changes to the architecture of the regulatory ecosystem. Asserting central government control over the industry has required the creation of new instruments of governance. Affairs considered issues of industrial decision making, now are regarded as aspects of public regulation. This study shows that the expansion of public control does not come in the form of administrative centralisation, but a reorganisation around knowledge brokers that work with or for regulators directly.

The main contribution of this institutional analysis is the empirical definition of a regulatory ecology beyond actors with formal regulatory authority. This section shows that state authority is commonly fragmented, and that this fragmentation is associated with specific competences and expertise. In China, engineering institutes are regulatory actors overlooked in the literature, while in Mexico, the presence of an independent SO dominates the configuration of the entire ecosystem.

The analysis of the structure of the ecosystem shows that regulators do engage in extensive knowledge exchange beyond that of the asset-owners targeted by regulation, and especially manoeuvre to source alternative knowledge from that of the state-owned incumbent companies. This does not mean less state control, but rather regulators relying on the brokering position of different actors, distinctively the ISO and EOs allied to the ISO in Mexico, and the engineering institutes and other state created EOs in China, which serve as source and brokers of knowledge.

5.2.1 China

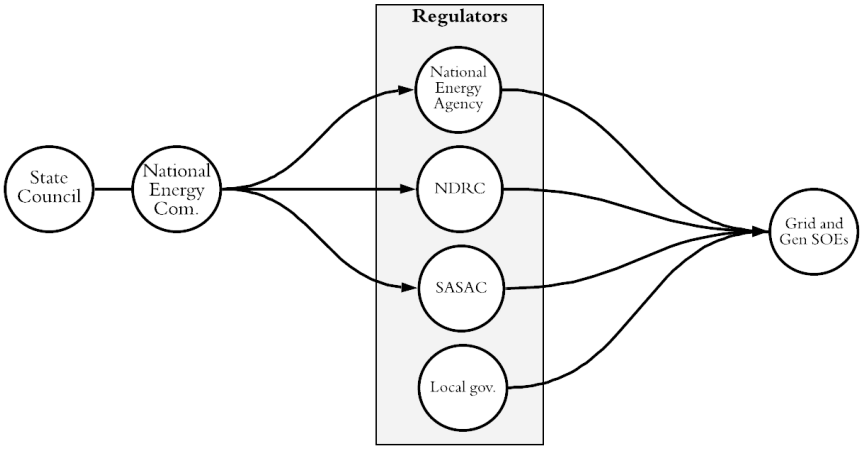
The State Council authority resides above other actors in the governance of the electricity industry, including multiple ministries, the National Development and Reform Commission (NDRC), the National Energy Commission, and the State-owned Assets Supervision and Administration Commission (SASAC). In 2010 the State Council created the National Energy Commission (NEC) presided over by the Premier to oversee the multiple dimensions of energy policymaking, not only electricity. Not long after, in 2013, the regulatory agency SERC was dismantled signalling the definitive move away from the model of an economic regulator of competition to drive the development of the industry (Tsai, 2014). The National Development and Reform Commission (NDRC), the Ministry of Finance (MoF) and the National Energy Agency continued to govern the industry through, respectively, short-term planning, tariff and subsidies policy, and operational regulation and project approval. The National Energy Commission was not reported by any

interviewee. This can be explained by the nature of NEC as a coordinating body within the State Council, which is observed by stakeholders and knowledge-holders as the Council itself.

State-owned companies act with relative autonomy from national regulators, like the National Energy Agency, if not from the state itself. Most of the assets are owned by companies under the direct control of the State Assets Supervision and Administration Commission (SASAC) which, as the primary shareholder, is concerned with maximising income from the companies (Feng, 2015; Leutert, 2020; Xu, 2017). In additional, provincial-level authorities hold independent authority and specific roles in the short-term development of the industry. And simultaneously, industrial corporations act independently, based on the revenue-maximising principles, to steer their own investment trajectories.

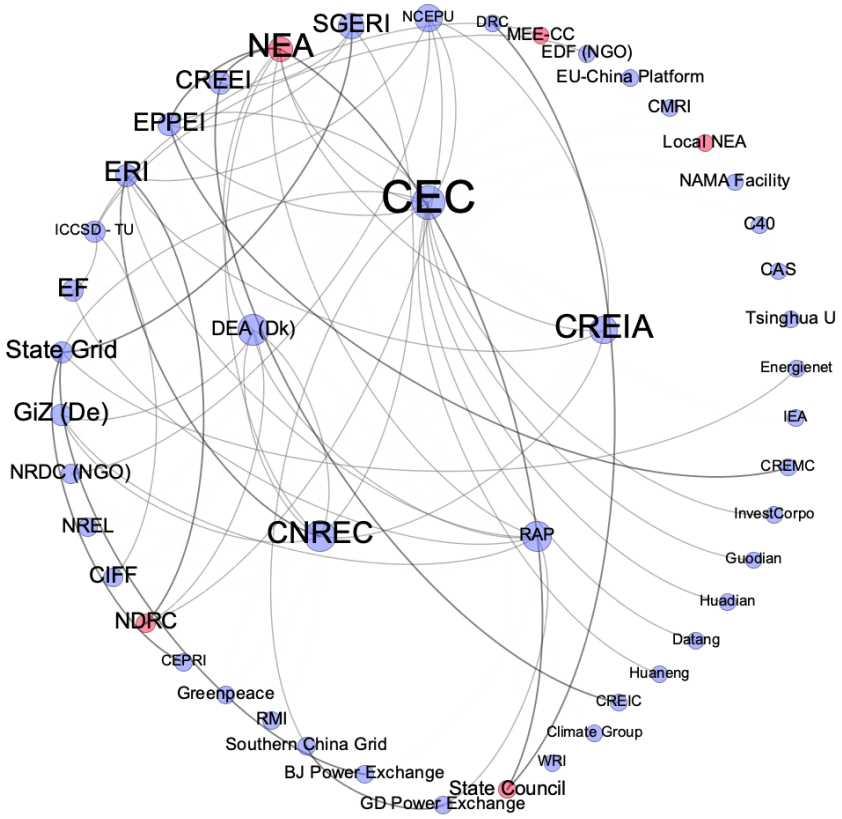
Neither the 2015-17 reforms or the more recent mandates to continue improving planning and dispatching activities were able to transform the structure of the industry significantly. At the same time, there has been an increase of centralisation at the dispatching centres in Beijing (for the control area of the State Grid) and Guangzhou (for the control area China Southern Grid). Power exchange centres have also gained certain autonomy and centralisation in Beijing and Guangzhou. Figure 5-2 provide s graphical representation of these relationship.

Figure 5-2. Hierarchy of public authority in China in 2018



The network elicitation exercise provided information to establish a different representation of relevance, other than the formal delegation of authority and roles in a hierarchical structure. An important finding is that there are few reported linkages to the State Council. This is not a surprise

Figure 5-3. Network graph of knowledge exchange in China



Main acronyms

CEC: China Electricity Council.
NEA: National Energy Agency.
CREIA: China Renewable Energy Industries Association.
CNREC: China National Renewable Energy Centre.
ERI: Energy Research Institute.
CREEI: China Renewable Energy Engineering Institute.
SGERI: State Grid Energy Research Centre.
EPPEI: Electric Power Planning and Engineering Institute.
CIFF: Children's Investment Fund Foundation.
GiZ(De): German Development Cooperation Agency.
DEA(Dk): Danish Energy Agency.
EF: Energy Foundation.
NDRC: National Development and Reform Commission.
BJ Power Exchange: Beijing Power Exchange centre.
GD Power Exchange: Guangzhou Power Exchange centre.

Due to the nature of the research design and structure of the interview it was expected that government regulators, NEA and NRDC would be among the most highly interconnected. This was not the case. Reported linkages to the National Development and Reform Commission (NDRC) were also relatively few, despite its central position as macroeconomic policymaker and

orchestrator of pricing and market reforms. As mentioned previously, the disappearance of the State Electricity Regulatory Commission in 2013 can be directly related to the pre-eminence of the NDRC economic regulator and policymaker (Tsai, 2014). Several actors report linkages to the Energy Research Institute and the China Renewable Energy Centre. In particular, CNREC is reported to be the most central actors to EOs, both foreign and local, specifically working on renewable energy policy and planning. Interviewees reported working with CNREC as the most direct approach to influencing or contributing to NDRC decision making. As explained by two interviewees, CNREC has been delegated with convening the consultations on renewable policy reform (2B03, 2C05).

Two prominent local actors are two trade associations, the China Energy Council (CEC) and the China Renewable Energy Industries Association (CREIA). In particular, CEC serves as the voice of the largest incumbent players, and in particular of the State Grid Corporation –which not only physically hosts CEC in one of its Beijing offices, but also provides CEC with leadership in former CEOs. Interviewees reported relating to these association for the development of joint projects for translating and adapting industrial knowledge from other jurisdictions on topics like feed-in-tariff structures, and industry-lead initiatives like the corporate purchase of clean energy. But the CEC does more than representing the industry. In fact, most of the statistics used in the literature, within and outside China, rely on information and reports provided by the CEC.

Table 5-1 presents a number of scores that characterise the position of each actor within the network graph as knowledge receivers (In-degree and Authority) or providers (Out-degree and Authority). This table refers to the top five actors for each score to highlight the relative importance of actors.

The In-degree and the Authority scores provide relatively different ordering of importance. In the case of reported in-degree the industry associations CEC and CREIA are more or less as interconnected as the regulator NEA and the policy research institutes CNREC and ERI.

However, the Authority score reposition CNREC, NEA and ERI at the top, only followed by knowledge-based foreign organisations, ERI and the Energy Foundation. The absence of the NRDC as a regulator is noticeable, along with the relevance of the policy research institute ERI and CNREC, which stands between NDRC and most actors.

Table 5-1. Structural position scores in China

In-degree score

Acronym	In-degree
CEC	12
NEA	7
CREIA	7
CNREC	6
ERI	5

Authority score

Acronym	Authority
CNREC	0.40
NEA	0.38
ERI	0.34
GiZ (De)	0.33
EF	0.26

Out-degree score

Acronym	Out-degree
DEA (Dk)	12
RAP	12
NCEPU	10
CNREC	8
SGERI	5

Hub score

Acronym	Hub
RAP	0.55
NCEPU	0.44
DEA (Dk)	0.40
CNREC	0.34
CREIA	0.26

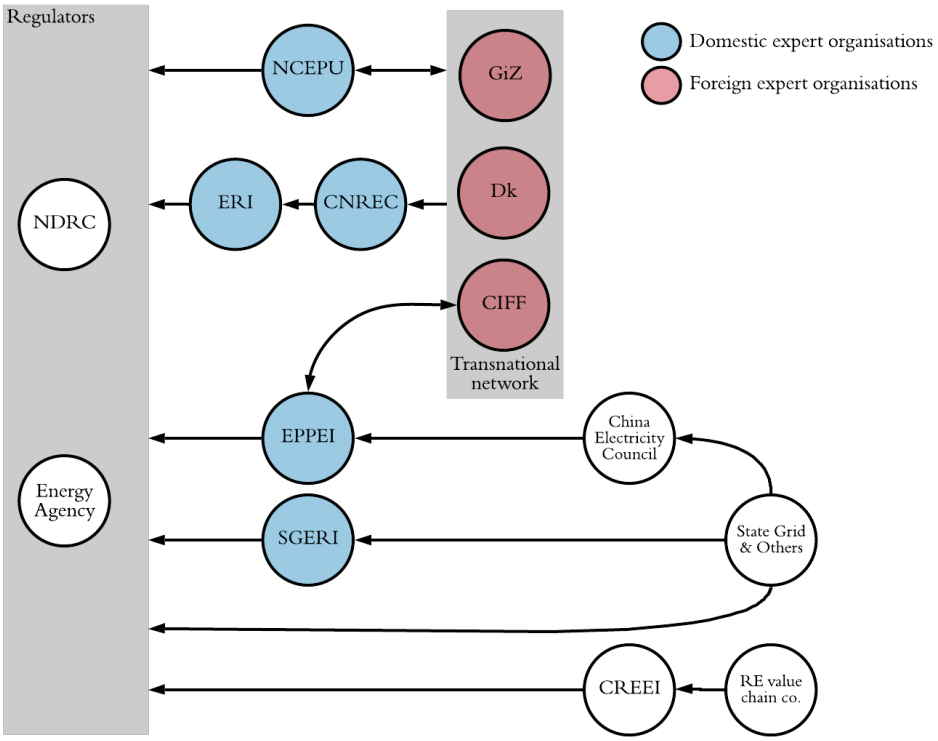
The out-degree and hub scores provide a more consistent perspective of sources of specialised knowledge. The foreign Danish Energy Agency, the US-based RAP, and the local North China Electric Power University (NCEPU) and CNREC hold the highest scores in both indicators as providers of knowledge. The most relevant and significant finding from this analysis is the CNREC's position as an authority and a hub.

These individual scores are still insufficient to point to the relevance of other knowledge brokers. With no interviews with the engineering institutes, the network graphs do not adequately represent the significance of the engineering and design institutes EPPEI and CREEI. These research institutes are older than the Energy Commission, the Energy Agency, and outlasted the now defunct State Electricity Regulatory Commission. EPPEI, CREEI, SGERI, along with the China Electric Power Research Institute (CEPRI) evolved from the unbundling of the State Power

Corporation of China in 2002. SGERI and CEPRI were attached to the State Grid, EPPEI and CREEI to the State Council to be able to service the entire industry.

Figure 5-4 provides comprehensive representation of pathways of knowledge exchange between these multiple actors, specifically including industrial associations and expert organisations. In China the knowledge provision is nested within local research institutes. In addition, they might collaborate with other actors, like the EPPEI or the North China Electric Power University. These institutions are able to integrate into transnational networks and at the same time as they embed the foreign segment of the network into a local environment. The Chinese government enlists these institutions permanently, as for the ERI or EPPEI, or welcomes foreign contributions through them. While there are more than a dozen foreign actors attempting to influence policymaking for decarbonisation in China, this diagram pictures the three most salient in fieldwork. These are the German and Danish cooperation programs, as well as the private Children's Investment Fund Foundation. These three actors' effectiveness resides in their involvement with CNREC.

Figure 5-4. Paths of expertise brokerage in China



Asset-owners rely on little intermediation, the State Grid and other companies can advocate for their preferred policies directly with the State Council, the NDRC and the NEA. However, they do pool competence resources though institutions like the State Grid Energy Research Institute of the China Electricity Council. The engineering institutes sit between the industry and the regulators, and increasingly foreign expert organisations and regulators. CNREC also became a well-established bridge between domestic and foreign expert organisations and regulators. The following review in Mexico will show significant differences to these institutional arrangements.

5.2.2 Mexico

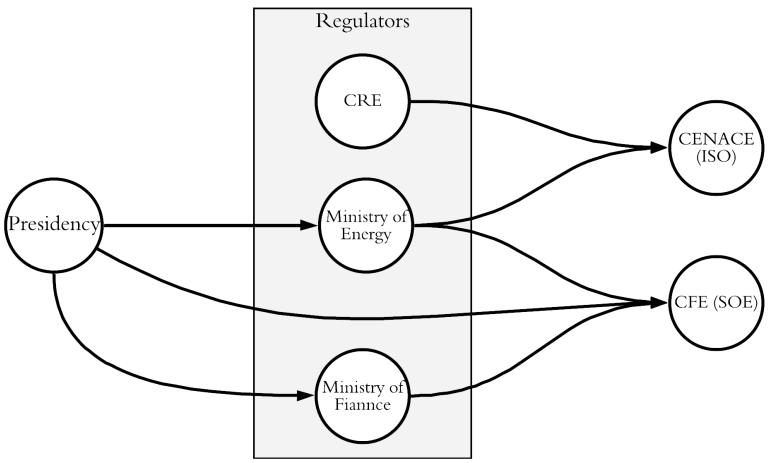
In Mexico the office of the Presidency is responsible for overseeing the development of the electricity system. However, all powers are delegated to the state-owned CFE, and the Ministry of Energy, and the autonomous regulator CRE. CENACE is formally under the legal remit of the Ministry of Energy with technical and administrative autonomy. In addition, the Ministry of

Finance still holds relevant authority over regulated tariffs and budget and investment decisions from state-owned companies. Figure 5-5 presents these hierarchical relations.

CRE holds a wide spectrum of regulatory authority over the entire industry, including the system operator CENACE. It is formally independent from the Ministry of Energy, as commissioners are appointed through the presidential nomination of a pool of candidates and congressional selection.

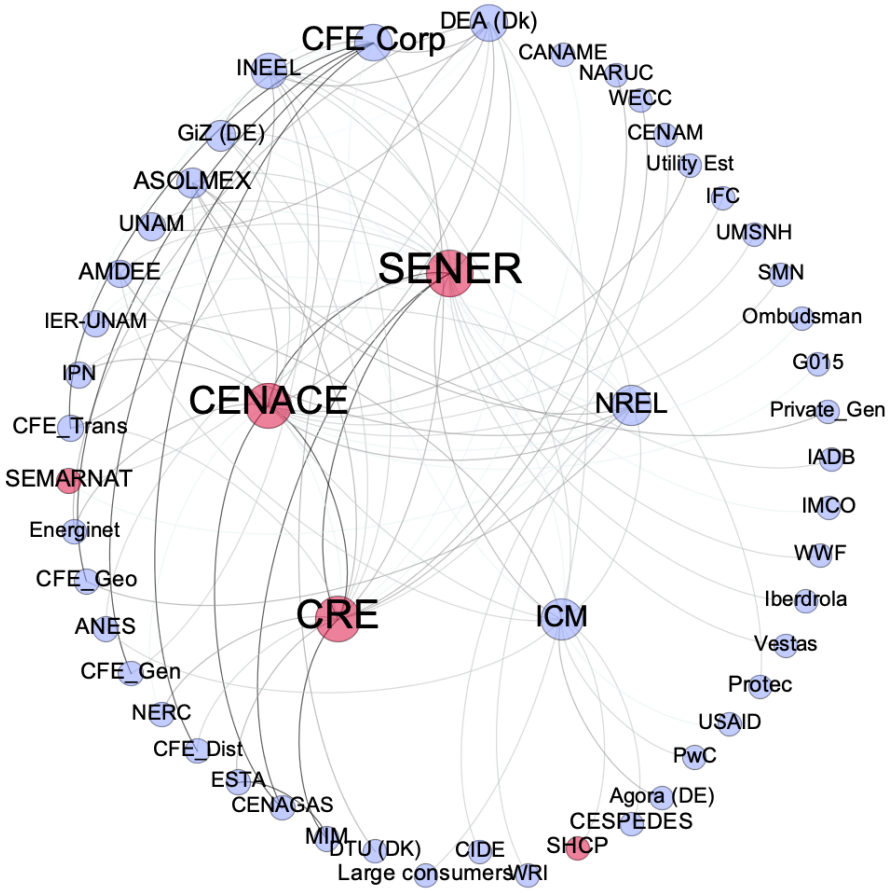
Institutional reports have stressed the expansion of market competition and private investment across the value chain but disregard the relevance of centralisation of political authority by the Ministry of Energy (IEA, 2017; Wood, 2018). The reduction of entry barriers is not equivalent to deregulation. In fact, the reform entails a process of extensive regulatory expansion (Hernández Ochoa, 2018). And from a governance perspective, the most meaningful change from the 1990s model to late 2010s model is, precisely, the new authority in the hands of the Ministry of Energy. This new authority allows the SENER, for example, to choose the transmission expansion projects and investment model. The Ministry of Energy took upon itself the responsibility of market reform implementation which other jurisdictions delegated to specialised agencies –such as Ofgem in the UK.

Figure 5-5. Hierarchy of public authority in Mexico in 2018



The knowledge exchange network elicitation presents a very different perspective by integrating all actors regardless of their formal role in the electricity system. This network graph highlights the actors with the largest reported numbers of inbound and outbound relations regarding knowledge exchange through larger circles and labels for easier inspection. The diagram denotes regulators in red with all other actors in blue.

Figure 5-6. Network graph of knowledge exchange in Mexico



Main actors

SENER: Ministry of Energy

CENACE: National Energy Control Centre.

CRE: Energy Regulatory Commission.

CFE Corp: Federal Electricity Commission - Corporate

NREL: National Renewable Energy Lab (USA)

I*CM*: Mexico's Climate Initiative

ASOLMEX: State Grid Energy Research Centre.INEEL: National Institute of Electricity and Clean Energy.

GiZ(De): German Development Cooperation Agency

DEA(Dk): Danish Energy Agency.

IER-UNAM: Renewable Energy Institute- National University.

AMDEE: Mexican Wind Energy Association.

MIM: Independent Market Monitor.

The Ministry of Energy (SENER) and the Regulatory Commission (CRE) are well connected and receive knowledge from a large number of actors in the system. In a model of full delegation from the political authority SENER to the technical and economic regulator CRE. While SENER and CRE have an equivalent number of linkages, it is indeed the case that CRE has stronger relations, showing the importance of this delegated authority. But CENACE, the system operator, is as interconnected as the Ministry and the regulator.

The relevance of CENACE shows that the governance system has evolved in a way that created parallel delegation chains. For many actors, working with and influencing policy through CENACE seems as important as working with the regulator. CFE only appears to be relatively highly interconnected because of the subsidiaries it represents. A very limited number of actors reported strong relationship with CFE.

There are three foreign expert organisations that play a very relevant role as knowledge brokers, the Danish Energy Agency, the German agency GiZ, and the US-based National Renewable Energy Laboratory. There are a number of active domestic knowledge sources, but two stand-out, the central government research institute INEEL and the advocacy organisation ICM. Other sources include universities and research institutions.

Table 5-2 present the descriptive statistics for several of the actors that are most relevant in knowledge exchange. The in-degree and the authority scores show a similar ordering of actors, with SENER at the top, as well as CENACE, the Corporation head of CFE and the local advocacy organisation ICM. One important finding is that based on the model of autonomous regulatory agency, CRE should have been the actors with the highest score, and possibly CENACE should have not appear with such a high score, especially compared to that of the regulator.

Table 5-2. Structural position scores in Mexico

In-degree score	
Acronym	**In-degree**
SENER	18

Authority score	
Acronym	**Authority**
SENER	0.57

CRE	16
CENACE	15
CFE Corp	10
ICM	7

CRE	0.46
CENACE	0.45
CFE Corp	0.35
ICM	0.22

Out-degree score

Acronym	Out-degree
INEEL	9
DEA (Dk)	9
ICM	7
NREL	7
GiZ (DE)	5

Hub score

Acronym	Hub
INEEL	0.41
DEA (Dk)	0.37
GiZ (DE)	0.35
NREL	0.26
ASOLMEX	0.25

The out-degree and hub scores provide a complementary story from the sources of knowledge. In this case, in terms of knowledge provision, the list of actors is headed by the domestic research institute INEEL, with three foreign knowledge holders, the Danish Energy Agency, US NREL and German GiZ, and the addition of the active advocacy organisation ICM. However, the weighted hub scores change the order and, most importantly, displace ICM out of the top 5.

This empirical research exercise is used to further stylise the understanding of governance roles and relations while emphasising relations of knowledge exchange. On the one hand, the industry, highly focused on the generation business provides specialised knowledge directly through CFE as a single corporation. Interviewees report that the relation to regulators is, in fact, managed by the corporate office and not independently by the subsidiary companies –undermining the weak evidence for the unbundling of the firm. The actors represented in Figure 5-7 were selected because of their prominence in the exercise to elicit linkages but have offered specific contributions to solving problems of renewable energy integration.

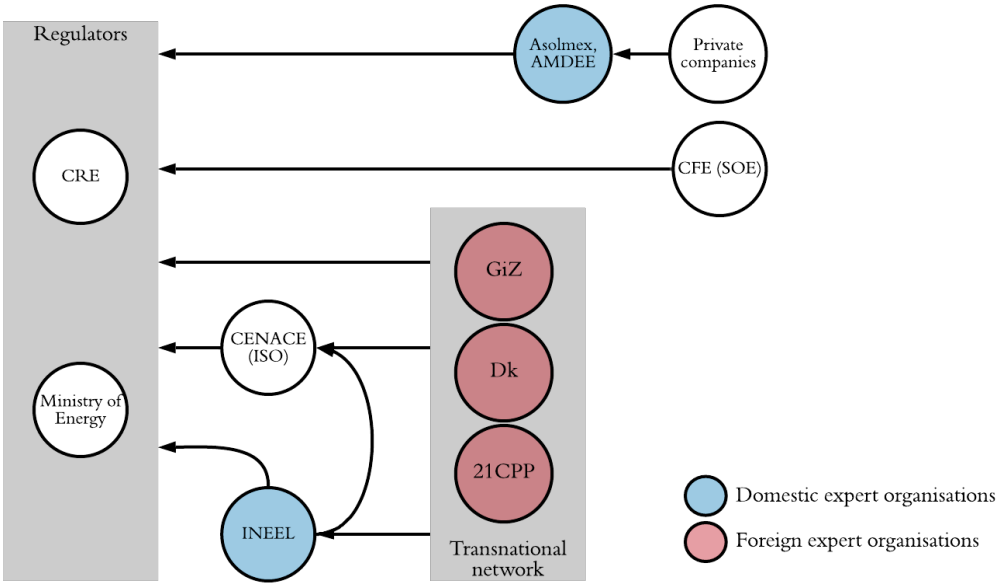
Private actors work through a number of trade associations with a technology-specific agenda, for example, on wind energy or solar energy. The solar-focused ASOLMEX and the wind-focused AMDEE have become effective voices that gather, process and produce usable knowledge for the regulators. This has been documented by other researchers as well.

This research elicits the importance of a number of expert organisations, both domestic and foreign. Contrary to the most visible type of formal international cooperation, this research found

the existence of transnational networks with a certain level of collaboration with CENACE and not necessarily with regulators. The German GiZ, the Danish climate cooperation program and the 21 Century Power Partnership (the umbrella for NREL and CIFF) all reported more impactful work when contributing within the remit of CENACE.

The National Institute of Electricity and Clean Energy (INEEL) also appears to offer an opportunity embed research within local capabilities and local knowledge users. It was possible to document with significant granularity the ways in which INEEL became a knowledge broker, whose capabilities enable SENER, CRE and CENACE to resolve relevant problems of liberalisation and the expansion of renewable energy and even to adjudicate conflict between these three government actors.

Figure 5-7. Paths of expertise brokerage in Mexico



This structural analysis shows that industrial actors rely on little intermediation, as trade associations are only a coordination mechanism for private companies and, as such, provide little knowledge other than the expression of their preference. Secondly, the evidence shows that foreign expert organisations have active direct relationship with regulators or work with domestic expert organisations, but that the involvement with CENACE is the most impactful avenue for contribution. Thirdly, the independent system operator is one of the most important knowledge

brokers in the country, mediating knowledge between domestic and foreign knowledge holders and the regulatory authorities. CENACE has the capabilities to acquire, process and utilise this knowledge.

Having completed this analysis of the organisation of the regulatory ecology, the next three sections present the process-oriented analysis. The process analysis is crucial to prove the existence of broker positions and the relevance of SOs and EOs as sources of knowledge. This analysis instantiates the existence of knowledge asymmetries and the production and exchange of regulatory knowledge.

5.3 Enlisting or appropriating the system operator

This section is dedicated to presenting the process tracing on the role of system operator. The Mexico case provided evidence of the relevance of the system operator's independence in fostering renewable energy expansion. China's ability to respond to its curtailment crisis would signal that independent system operators are not a necessary condition for success. However, a growing salience of system operators as crucial organisations in Chinese policy implementation speaks of the latent importance of this knowledge broker.

System operators not only broker knowledge from their own industrial expertise but, in fact, can become brokers of other actors' knowledge, a key node within a chain of knowledge sharing. When system operators are independent of the grid company, as in Mexico, they are entrusted with key regulatory functions on the basis of their own knowledge and become the central brokers in the ecosystem. Their new regulatory roles, compounded with their technical capacity, makes them targets for the most sophisticated forms of collaboration with other domestic and foreign knowledge-holders. The comparison between Mexico and China makes explicit the weight that the grid company has while having control of system operation, and provides insight into changes to come as system operation organisations gain relative independence.

In Mexico, the appropriation of the system operator was an explicit element of the reform strategy, with the unbundling of the control centre, CENACE. This resulted in a direct relationship between the Ministry of Energy and CENACE that did not exist prior to the reform. The presence of CENACE created a new parallel regulatory chain, through which SENER can delegate regulatory authority, bypassing the formal regulator CRE. Implementation of key renewable-enhancing regulatory innovation did not require the cooperation of the state-owned company and, more importantly, neither did the economic regulator.

In China, there has not been a similar appropriation of the system operator. However, there has been a modest process of unbundling. Since 2015 there has been a process of progressive unbundling, through functional differentiation between dispatching and trading centres from the rest of the grid companies, State Grid and Southern China Grid. By 2020, the grid companies will divest from the control of the dispatching centres in Beijing and Guangdong. Absent fully autonomous system operators, other actors that are not the grid companies perform several of the functions held by system operators. These functions include mediating information and knowledge between the industry and the regulator, as shown by the China Electricity Council playing authority roles. Regardless of the relative level of independence, system operator organisations must be involved with the implementation of regulatory innovations. Their relative independence, however, explains their relative leadership over implementation.

Figure 5-8 draws the relations between SOs and other actors. In China, the Beijing and Guangdong power exchange centres have become prominent in the regulatory process, as they spearhead inter-provincial market integration. However, in the interviews conducted, only one explicit project was mentioned between an international knowledge-holder, the Regulatory Assistance Project and the Guangdong centre.

Figure 5-8. Broker position of SO in China and Mexico

China

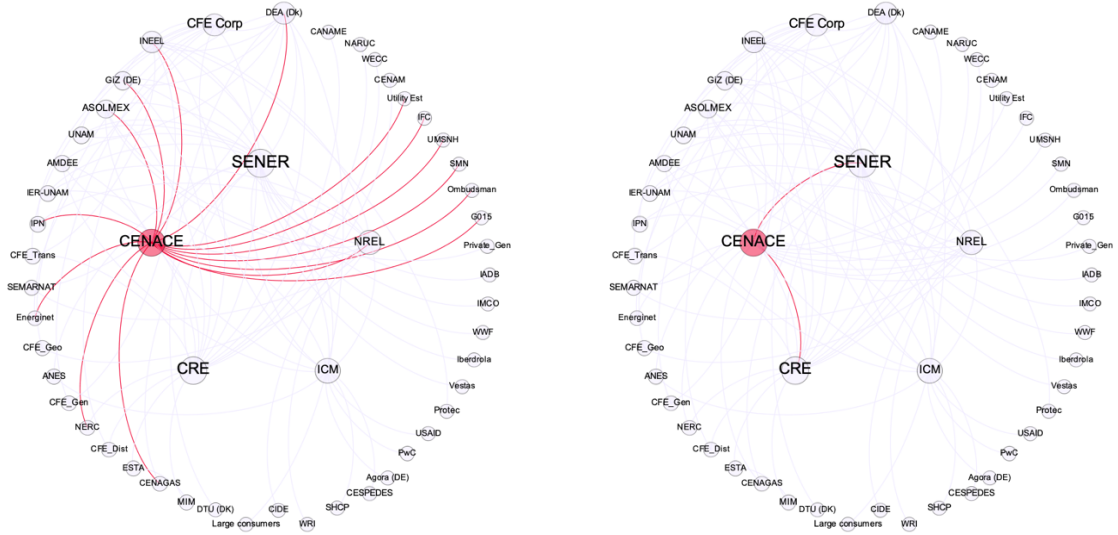
SO Inward SO Outward



Mexico

SO Inward

SO Outward



CENACE benefits from a large number of interactions with knowledge holders, both foreign and domestic. Actors like the German development cooperation agency GiZ, the Danish grid company Energienet, and the domestic National Institute for Electricity and Clean Energy (INEEL) are examples of highly skilled knowledge holders. Based on the interviews and the documental review, some of these knowledge holders did not have relations to the regulators directly, for example, the highly specialised power engineering department of the National Polytechnic Institute lost its relation to the Regulatory Commission, as they lost the contact for independent market monitoring services to an international firm (1A01, 1A09).

Table 5-3 presents a summary of the comparison on the role of the independent system operator in Mexico, and similar functions in China performed by other actors, within different areas of regulatory innovation.

Table 5-3 SOs and regulatory innovations

Regulatory innovation	Mexico	China
Market reforms	National system operator CENACE	Regional dispatching and trading centres (State Grid and Southern China Grid)
Central contracting		
Planning		China Electricity Council
Monitoring		-

Source: Author.

As previously discussed, Mexico underwent a very rapid wholesale market implementation in a period of only three years. SENER was the political authority tasked with enlisting other organisations' competence for the purpose of defining new market rules and implementing industrial reorganisation and instrumentation. But contrary to the experience in most liberalised markets, this was not done through the independent market regulator CRE. In this research, I was not able to establish whether the cause was political cleavage or lack of competences from CRE.[10] In any case, it seemed improbable that SENER would have ceased delegating implementation to CRE, if not for the availability of an alternative source of competence.

SENER's initial preference was to contract the market implementation to an international technology provider, like General Electric. But these firms established working timelines that would go beyond what was politically preferable to the incumbent government (1C10). At that

[10] The Ministry of Energy saw significant political risk in delegating these tasks to the regulator. At least one interviewee well place to inform about the position of the Ministry of Energy considered CRE had not built sufficient capacity for implementation.

point, CENACE took over the responsibility of market implementation, bringing along with it the participation of a local technology provider that had long-time relations with CFE and CENACE, the National Institute on Electricity and Clean Energy (INEEL) (1C09, 1C10, 1B03).

Formally, CENACE is itself a target of regulation. Their responsibilities are established in market rules first defined by SENER and revised by CRE. However, in practice, the rules of CENACE operation were defined based on many of their pre-existing operating procedures. The formal rules were drafted by CENACE with the support of INEEL, based on the features of the computer applications and operation practices that had previously been established for economic dispatch (1C09, 1C10). In the most literal sense, CENACE became a rule maker.

A second instance of CENACE prominence was the launch of the long-term energy auctions, which are considered the main device for renewable energy expansion. Long-term energy auction is by no means a general feature of liberalised markets. In fact, by certain accounts, these instruments are actually inconsistent with the principles of a liberalised energy market (Keay & Robinson, 2019). One informant reported that one of the principal advisors to SENER, an energy economist at the University of Harvard, advised against its use (1B09). The preferences of SENER were for a mechanism which allowed for the expansion of clean energy in a way that was the most similar to free markets and resulted in the lowest possible price tag per MWh (1B09).

Based on CENACE's capabilities of implementation, the auction included a rare mechanism for rating generation offers based on the geographic differences in predicted future local electricity prices. The adjustment factor favoured projects in regions of the country with poor energy supply. While this adjustment mechanism arguably attempted to mimic plausible investment choices as if they were taken in electricity markets, in fact, it conditioned the development of the sector to planning choices made by CENACE and SENER staff. CENACE and SENER co-designed the auction rules with the support of external consultants, but the implementation of the algorithm depended solely on CENACE. Similarly, CENACE provides the basis for the development of

adjustment factors that are used to weight the energy plus certificates offered based on expected long-term energy prices.

Several authors and interviewees report that the most recent focus of the policy reform is to improve inter-provincial trading and the establishment of spot-markets (2C10, 2C07, 2C05). In practice, this entails that a system operator must be able to (1) have larger control over deciding how much and at what time inter-provincial transmission infrastructure is utilised (2C010), and (2) change the scheduling of utilisation of power plants with a higher frequency than currently done up to the point of achieving a dispatching system that resembles real-time spot markets (2C07 and Davidson 2019). However, a voice from the industry strongly argued in favour of the first, while undervaluing the relevance of the second (2B01) in agreement with the public preferences from the State Grid Company (Wang, 2017).

In combination, both measures require reducing the scope of autonomy of the branches of the grid company and the local authorities in using administrative planning (GiZ & CNREC, 2019). But it also requires the implementation of new industry practices. Under the 'fairs-dispatch' principle, dispatching is scheduled one week ahead of the start of every month for the entire month (2B01), after which there are one-time daily revisions to the schedule (2B01). This work is divided geographically and functionally.

In contrast to Mexico, the system operation roles are fragmented into different actors that have, until recently, lay within the realm of control of the State and the Southern China Grid companies, which are the counterparty to the generation contracts. Before 2019, trading and dispatching centres were owned by grid companies and large generation companies, with majority ownership from the State Grid and the Southern China Grid, each within their own control areas.

In 2015 the government decided to increase the amount of generation dispatched beyond the plan from outside province sources, and therefore, beyond the 'fair dispatch principle' (3B03). In 2019, a total of 30 percent of electricity was formally traded outside these plans (CEC, 2020). This

process has been led by the regional operation centres of the grid offices, in Beijing and Guangdong.

In these conditions, the relevance of dispatching centres is obscured by the superposition of the grid companies in the process of reform. However, in the future the increased formal independence of the power exchange and dispatching centres might lead to a situation more similar to the Mexican case, in which the state can rely upon both state-owned grid companies and directly accountable system operators for regulatory implementation.

If the independence of system operators appears to be a fundamental institutional reengineering for successful implementation, what conditions could explain success in the absence of an independent system operator? The next section will discuss the role of new and old domestic actors entrusted with regulatory roles on the basis of the knowledge they can provide the top regulators. CREMC and EPPEI are examples of these actors, which are particularly relevant in the case of China.

5.4 Creating, enlisting and contracting domestic expert organisations

Several domestic EOs have proven to be enablers of regulatory policymaking. A few were delegated regulatory roles by the authority due to their specific technical competences. As the previous section discussed, system operation independence appears to have provided the Mexican government with a capable ally in policy implementation for efficient renewable energy deployment. However, the achievements in limiting curtailment in China happened before significant unbundling, weakening claims that system operator independence is a necessary condition for successful regulatory innovation.

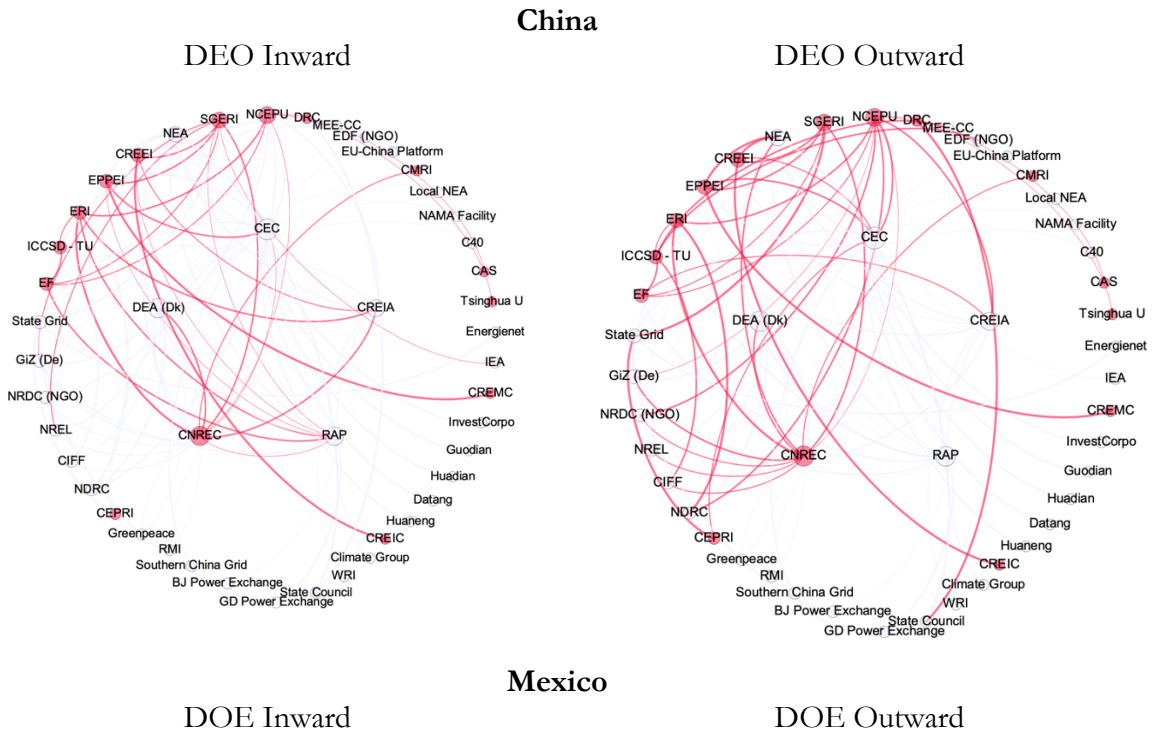
A second hypothesis is that the presence of expert organisations can increase the ecosystem's capacity for rulemaking, planning and implementation. This section provides evidence from domestic EOs. The analysis shows that the relevance of specific domestic EOs is the result of

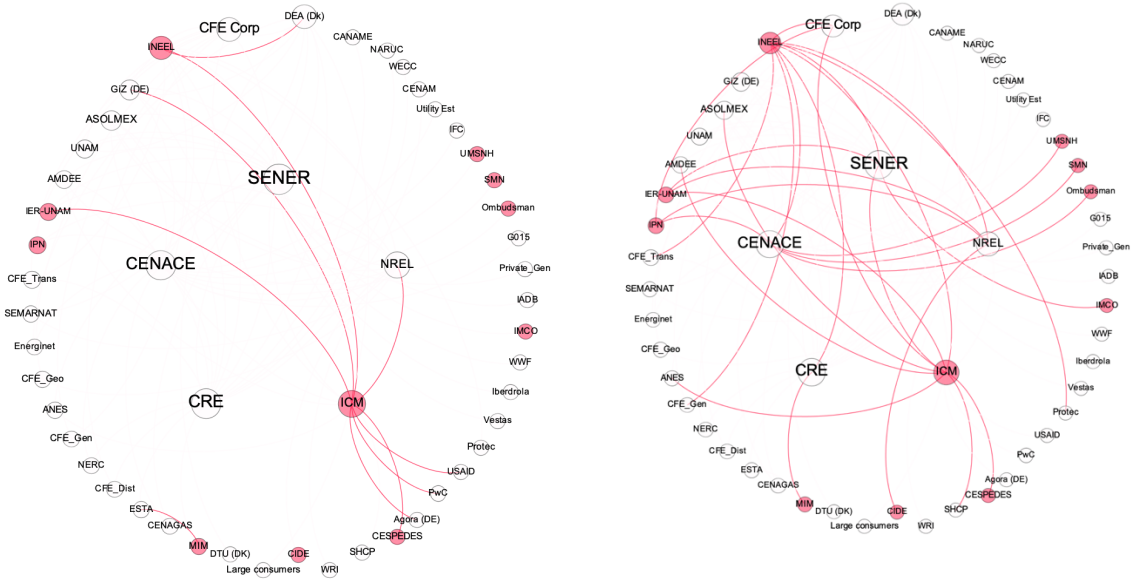
regulators entrusting them with mandates that are fundamental to implementing the policies that make renewable energy integration more effective. In the case of China, this extended to the creation of new actors.

This research found that expert organisations do increase regulatory capability. The evidence is stronger in the case of China, where domestic expert organisations have been delegated with regulatory roles due to their own particular technical skills. In Mexico, both domestic and foreign expert organisations appear to provide only support to regulatory processes but not leadership.

The Chinese central government has entrusted domestic expert organisations with roles which, in Mexico, would be developed by the system operator directly. These include grid expansion planning, monitoring of renewable energy expansion, and monitoring of compliance in the dispatching and system operation. In light of China experience, the Mexican case shows an untapped potential in developing governance capabilities through domestic expert organisations, given that domestic knowledge-holders importance has only eroded with the liberalisation. This contrast is already visible in the contrast of density of relations in China and Mexico in Figure 5-9.

Figure 5-9. Broker position of Domestic EOs in China and Mexico





For China, the graph shows that the most connected expert organisations are the Energy Research Institute (ERI) and the China National Renewable Energy Centre (CNREC) nested within ERI. Other institutions include the State Grid Energy Research Institute (SGERI), the Electric Power and Engineering Institute (EPPEI) and the China Renewable Energy Engineering Institute (CREEI).[11] As referenced in its name, SGERI is a policy and economic research arm of the State Grid. The State Grid company also holds China Energy Electric Power Research Institute (CEPRI) which is dedicated to technical research. SGERI does have active relations with peers among policy and engineering institutes, including CNREC, while CEPRI was only reported to have relations to the trade association the China Electricity Council, but within the State Grid provides technological services for system operation.

The network graph for Mexico shows a limited number of domestic expert organisations, knowledge-holders that provide support to the regulators and the independent system operator. These actors include the National Institute of Electricity and Clean Energy (INEEL) formally associated with the Ministry of Energy. The other domestic actors are the National Polytechnic Institute, the Renewable Energy Institute of the National University (UNAM) and two advocacy

[11] CREEI Chinese name 水电水利规划设计总院 can be translated as China Hydropower Planning and Construction Institute, however, all references in English use 'renewable energy' in substitution to 'hydropower'.

organisations, Mexico's Climate Initiative (ICM) and Energy Ombudsman, both of which partner with knowledge-holders in their routine work.

Table 5-4 presents a summary of comparisons in the areas of regulatory innovation and the knowledge-holding domestic transnational. In Mexico, the few actors that participate in the deployment of regulatory innovations had a diminishing relevance in the period under study (1C09, 1C10, 1A04).

Table 5-4 Domestic EOs and regulatory innovations

Regulatory innovation	Mexico	China
Market reforms	INEEL	EPPEI, Huabei, ERI-CNREC
Contracting mechanisms	-	CREIC
Planning	INEEL	EPPEI, CNREC, CREMC
Monitoring	INEEL / IPN	EPPEI, CREMC

The Electric Power Planning and Engineering Institute (EPPEI) and the China Renewable Energy Engineering Institute (CREEI) hold particular importance historically as technology service providers to the industry, and more recently explicitly to the authorities of the central government, the NEA and the NDRC.

While formally dependent on the State Council, historically, their working relations were concentrated on the grid and generation companies in the industry (Xu, 2017). Recently, however, they work more directly with the NDRC and NEA in the planning and monitoring of the electricity system. This has been done through specialised research centres created specifically to fulfil regulatory roles, within the research institutes. These are the National Renewable Energy Information Centre (CREIC) part of CREEI, and the National New Energy Consumption Monitoring and Early Warning Centre (CREMC) part of EPPEI. These two actors, CREIC and CMREC, reshape the knowledge landscape and have become increasingly visible in policy

documents and discussions due to the growing centrality of system planning and new forms of monitoring compliance. Finally, the China National Renewable Energy Centre sits within the NDRC's Energy Research Institute and has become a point of focus for long-term planning for decarbonisation of the electricity system, advising the NDRC on the cost and compensation policies and the mid-term targets for deployment of renewable and clean energy in the electricity sector.

It is important to stress that domestic expert organisations are not independent of incumbent interests that favour coal power generation. In fact, two interviewees discussed a recently published report from EPPEI arguing for the short-term expansion of coal power generation capacity to address the risk of supply constraints in the short-term (2C08, 2C04).

Implementing reforms to introduce markets was identified by all interviewees as key to fostering renewable energy. In practice they refer to different regulatory devices. For example, introducing wholesale markets would mean reducing allocated utilisation hours that have traditionally benefited coal power plants. Ad hoc solutions, like the trading of utilisation rights to compensate thermal power plants dispatched down to integrate renewable energy is just one example of regulatory innovation that seems to have proved effective (2C05, 2C06). The deployment of the policy is based on the dispatching centre's knowledge of the spare generation capacity very close to the real-time. But the policy decision was not necessarily based on the assessment of dispatching centres about their own capabilities, but rather on the knowledge of research institutes like EPPEI and the North China Electric Power University (NCEPU) about the conditions of operations (2C08).

In the context of a renewable energy quota, policy instruments like clean energy certificates and auctions are both market oriented. The future of renewable energy expansion seems to be the use of clean energy consumption quotas. The specific fix of policy solution must come from ERI and CNREC, including on the approach to achieve inter-provincial trading of clean energy and inter-

provincial balancing of renewable energy quotas (2C06). The designation of CNREC as the convenor of policy dialogue has meant that the Centre focalises transnational efforts for policy learning, even if ultimately NEA is the agency responsible for deploying regulation (2C10). The quotas for expansion of renewable energy and the benchmark prices that define the auctions depend on the analytical work of the China Renewable Energy Information Centre (CREIC). In 2020, the parent organisation, China Renewable Energy Engineering Institute (CREEI) was tasked with drafting the Renewable Energy 14th Five-Year Plan, coordinating the inputs from ERI, EPPEI, and the State Grid (DEA, CNREC, & ERI, 2020)

Planning can be used to inform policy and regulatory change as well as investment. The regulatory authority, NEA, has asserted its authority over investment planning by placing EPPEI at the delegated actor to conduct grid expansion planning (2B01).[12] The State Grid company has the capabilities and tools to develop these studies (Bo, 2018). Hence, EPPEI's formal position as convenor and author of expansion planning represents a constraint on the influence of State Grid. NEA's growing specialised planning bureaucracy (2C04) can work directly with EPPEI and other institutes in ways that would have not been possible before 2015.

The second use of planning is to influence the regulatory decision through the explicit use of scenario analysis. This work is fostered in China by CNREC with the support of international partners. Scenario-making is useful to understand the economics of successful transition and to identify the windows of opportunity to accelerate said transition (2C10). CNREC produces a yearly outlook which contains a survey of the latest developments and presents scenarios to 2050, to show the trajectories of current policy portfolio and the requirements of the international commitments under the Paris Agreement, for both electric power and heat (see CNREC, 2019). The work is independent of other workstreams of the ERI, and it also includes collaboration with

[12] The German Energy Agency DENA has increased direct collaboration and diagnosed the status of transmission grid planning in comparative perspective (Geman Energy Agency et al., 2019).

the macroeconomic researcher teams at NDRC to investigate the impact of macro variables, like employment and regional development (2A01).

As expressed by a former expert modeller from NEA, the work of CNREC could not be performed by NEA own experts due to the specificity of tools required for modelling an electric power system (2C03). Interestingly, due to EPPEI's closeness to the industry, there would have been serious concerns about biases in the results. This opens up an interesting subject of research: the competition between coalitions of regulatory agencies and their technical allies on policy development. If indeed NEA and EPPEI favour interests aligned to investment in overcapacity and protection of coal power generation (as reported by two specialised academics), the NDRC and its own ERI-CNREC represent a balancing source of influence focused on the consequences of ineffective deployment.[13]

Since 2017, the NDRC and NEA have increasingly asserted their authority, not through project approval or administrative planning, but as a regulatory authority. The system depends on the monitoring of economic and operative conditions to indicate the conditions for investment based on a red, orange and green indicator by province and for thermal, wind and solar energy projects (2C08). This analysis includes the assessment of the 2018-established curtailment targets. But these new governance tools depend on the work of domestic EOs. The red-light system and the monitoring of compliance with curtailment targets depend on the work of the National Renewable Energy Consumption Monitoring and Early Warning Centre (CREMC), created in 2018 as part of EPPEI to provide the specialised monitoring of the system. Despite its short life, by the summer of 2019, interviewees already considered CREMC as one of the most important think-tanks in the renewable energy sector (2B01, 2B03).

[13] Interviewee 2C04 noticed the parallelism of the National Climate Strategy Centre that works for the Ministry of Environment and Ecology and the EIR relation to the NDRC. These actors are able to directly make policy as they are embedded within the regulatory authority.

In light of the deep Chinese integration of research institutions into regulatory policy making and supervision, the Mexican case is characterised by very limited participation of domestic transnational networks. In fact, as discussed with interviewees in Mexico, during 2018, the contribution of domestic research institutes appeared to be diminishing after a very intense period of participation in 2014 to 2018. This was particularly the case for the National Institute of Electricity and Clean Energy (INEEL), which formerly provided the technological tools and services to the state-owned company's different business units, including on planning, generation scheduling, and grid operation and performance monitoring (1C09, 1C10).

Due to the high level of access to interviewees in Mexico, it was possible to document contrasting views on the participation of domestic research institutes. Some of these perspectives were highly critical. Interviewees in the public and private sector described the lack of capacities, lack of flexibility and time responsiveness, as well as the high costs of working with some of these institutions, in particular the INEEL and the National University (UNAM) (1B10, 1A03, 1A04, 1A06). The relations with SENER and these institutions showed little evidence of relevance. Similarly, the private sector associations and companies reported little collaboration with these types of institutions (1B02, 1B03, 1B05, 1B06).

Earlier, I discussed the role of CENACE role as a rule maker. Its work on drafting market rules depended on the support of INEEL. The computer applications and operation procedures were originally designed by INEEL for dispatch scheduling and market settlement procedures. This means that ultimately, INEEL was tasked with translating the operating procedures they had been designing into the rule book (1C09, 1C10, 1A01). Other segments of the market rules were developed by experts hired or consultants contracted by SENER (1A04).

However, CRE and CENACE hold different perspectives about these actors. INEEL appeared to have a very relevant role during the implementation of wholesale market reform as it provided support to CENACE and might have an occasional but growing relevance in relation to CRE

work (1C09, 1A05, 1A01). At the time of interview, CRE was expected to use INEEL models on interconnection and system operation in the region to prove that CENACE limits interconnection and hurts the development of the market (1A01, 1B05).

The tools that appear to be useful for CENACE and CRE in working with INEEL were dismissed by the SENER. The Ministry, in fulfilling its new responsibilities of planning coordination and the creation of 15-year indicative generation scenarios decided to utilise a commercial tool (Plexos), with the support of a consultancy from Chile and, later on, the support of the US-NREL experts in modelling (1C09, 1C10, 1C03, 1A04). This need not be uncommon. The Ministry is able to tap into a larger pool of expertise from an international community of users, rather than relying on a tool built for a unique purpose that might not be intended to be shared with additional users. As observed in the Chinese case, the lack of replicable models can result in a source of influence from incumbent interests.

For some actors, domestic research institutes and universities, in both Mexico and China, are considered expensive, inflexible and, for some, provide little more than rubber stamps to the status quo (1A03, 1B06, 1B05, 2C11, 2C03, 2C05). However, there is evidence of the relevant functions they are able to play if appropriately paced within the regulatory system. Other interviewees, more concerned with the technical challenges of renewable energy integration, referred to crucial contributions made in moments of reform, like the North China Electric Power University faculty idea for the use of a warning-system or INEEL codification of operations software.

These advantages accrued from their past work with the industry, the grid and generation companies. However, it would be most appropriate to consider this type of knowledge as a latent competence than is only realised through two related institutional conditions: when entrusted with a regulatory responsibility, and when brokering knowledge of foreign knowledge-holders.

Presuming EPPEI in China, and INEEL in Mexico are equivalently competent. EPPEI hosting the new National Renewable Energy Monitoring and Early Warning Centre is the result of an

explicit delegation of supervisory authority. This sets EPPEI and INEEL apart. Similarly, the importance of the China National Renewable Energy Centre lies in its position as an explicit hub for international collaboration. This section has discussed the delegation and contracting of regulatory functions. In turn, the next section discusses the ways in which foreign knowledge-holders engage in the ecosystem.

5.5 Engaging or nesting foreign expert organisations

Foreign expert organisations are knowledge brokers if their competence is based on the translation of other jurisdictions' experience and tools into the local conditions. A number of actors have been entrusted precisely with that mission, funded by official national cooperation programs as in the only CIFF has presence in both countries.

Foreign EOs come into domestic policy context with highly skilled teams carrying the legitimacy of other jurisdictions' success and the host government goodwill in international cooperation. They can broker both domestic and foreign knowledge. Not only do they have a network in the jurisdiction of origin, they can use their skills and funding to engage local expertise to work on new questions or new governance tools.

Their mission is to extrapolate experience from other jurisdictions or to produce governance solutions specifically tailored to a host country. It is important that their effectiveness be called into question. An interviewee well placed to comment on the benefits and drawbacks of the work of foreign expert organisations in Mexico starkly commented "Ninety-nine percent of all cooperation ends with a study. You take it to the policy-maker, to the regulators, give it to CENACE to look at the beautiful report in a drawer." (1B05). Similarly, we should not assume their irrelevance, as the same interviewee would explain when referring to one particular instance of knowledge brokerage in the first of a type of technology deployment in the country: "If there is no expertise in the country. Who should I look for? […] Luckily GiZ introduced a menu of

options and the people to orient us on the design, just as it happened with CRE, get the initial design first and then you can move on." (1B05).

The contribution of foreign expert organisations is dependent on the nature of their institutional nesting within the country. The process analysis case of GiZ from Germany or the cooperation programs from the Danish Energy Agency, both working in Mexico and China. Other funders, from private or public autonomous endowments, also articulate collaboration that enables the production and provision of specialised knowledge, as in the case of the Children's Investment Fund Foundation (CIFF), the Regulatory Assistance Project (RAP), and the Energy Foundation (EF). Amongst these examples

shows that their most valuable contribution does not take place when working with the regulator directly. Rather, the most relevant contributions derive from the joint development of knowledge and tools with domestic expert organisations. This means that their contribution depends on how they form chains of knowledge brokerage with domestic actors.

These relations are visible in the number of inward relations depicted in the network's graphs of Figure 5-10. In China, DEA and RAP are already some of the most interconnected actors this is largely due to their reliance on collaboration from domestic EOs, in particular researchers in universities, and also other foreign EOs. Similarly, in the case of DEA and NREL there is a significant reliance on local expertise. But not all foreign EOs necessarily show the same patterns, some of them because they are not formally active in the country, but simply bridge knowledge from other jurisdictions in international settings, as is the case of the International Energy Agency (IEA). Simultaneously, foreign EOs contribute to the work of domestic EOs in both cases, but especially in China due to the density of the domestic EO ecosystem.

Figure 5-10. Broker position of Foreign EOs in China and Mexico

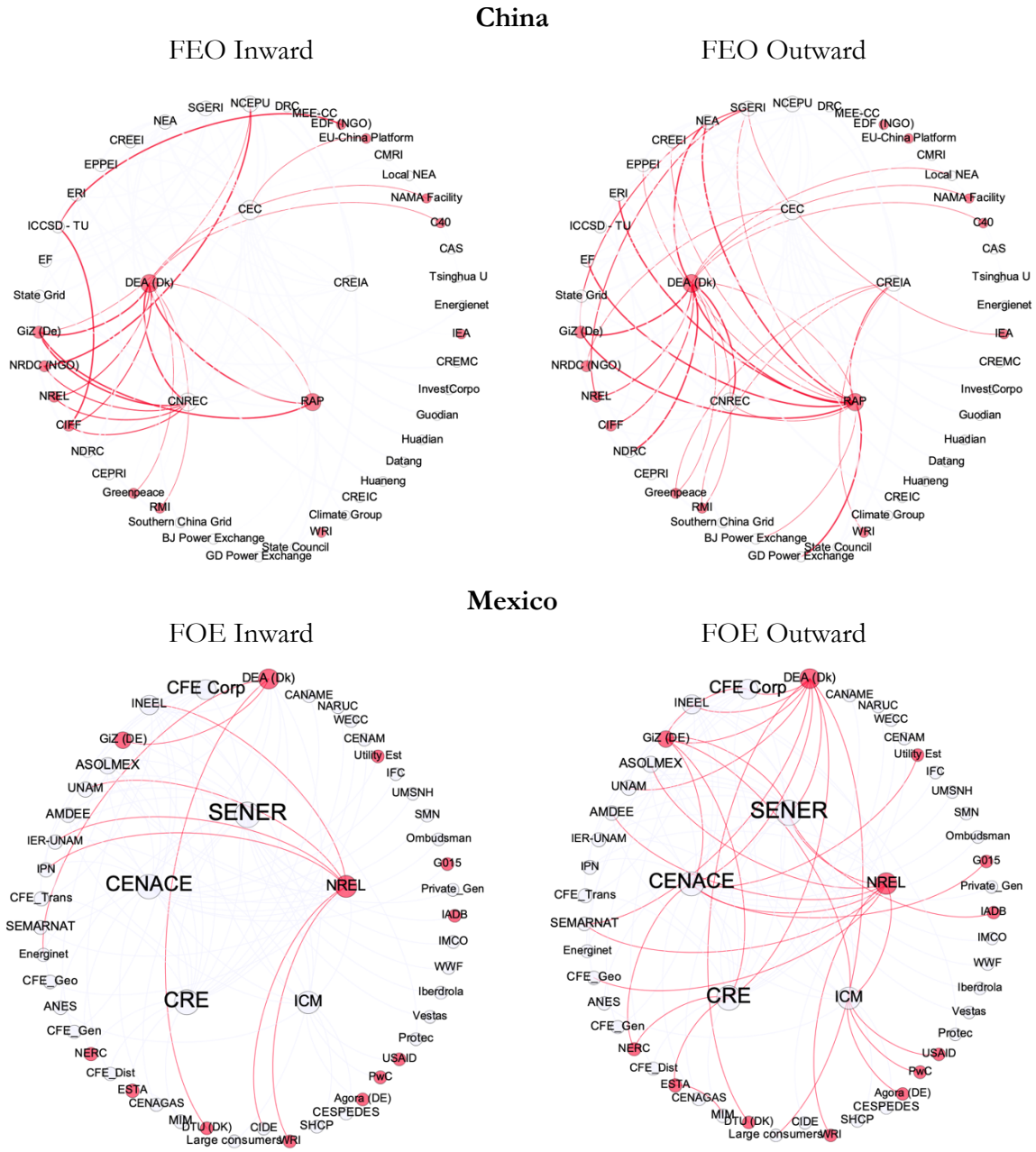


Table 5-5 summarises the presence of foreign knowledge-holders is the three instances of regulatory innovation selected to track specific processes of decision making. As this diagram shows, Mexico and China benefit from the work of a few relevant foreign actors working on electricity decarbonisation: the Danish Energy Agency (DEA), the US-based National Renewable Energy Lab (NREL) and the German cooperation agency GiZ. In addition, China benefits from the participation of other private actors, including the Regulatory Assistance Project (RAP) and

the Children's' Investment Fund Foundation (CIFF). This list is not exhaustive. There were other actors named in interviews, but whose role I was not able to document with sufficient detail. In some cases, tight transnational networks and delegation might hide the participation of certain actors. For example, in Mexico, the participation of NREL is paid and supported by the CIFF. However, interviewees only identify NREL as the actor they engage with as part of a multilateral initiative under the name of 21st Century Power Partnership.

In China, the structure of relations is distinguishable due to the significance of the relations with CNREC, as virtually all participants consider CNREC the main or one the main focus of attention. Relations from foreign knowledge-holders are more dispersed, working with NEA and NDRC is important, but also with the trade association CEC and CREIA, and with the research institutes SGERI and EPPEI.

Table 5-5 Foreign EOs and regulatory innovations

Regulatory innovation	Mexico	China
Market reforms	DEA	GiZ, DEA, RAP, CIFF
Central contracting	Private consultancies	
Planning	DEA, GiZ, NREL	DEA, GiZ, CIFF NREL
Monitoring	-	-

Source: Author.

Foreign EO relation with the regulators might not have a significant impact, unless accompanied or mediated by a domestic EO. Interviewees reported foreign EOs had impacts in the decision-making process by building chains of knowledge brokerage. In Mexico, the relationship that matters the most is with the system operator. In China, it is with the domestic knowledge holders: CNREC, the engineering institutes, and the key specialised universities.

From the perspective of foreign knowledge holders, China has multiple points of contact for collaboration due to the formal separation of Power Exchanges, the expansion of the role of the

China National Renewable Energy Centre and of the regulatory supervision roles. However, as mentioned by almost all interviewees, CNREC has served as the host of many opportunities to contribute to the regulatory policy making for reform.

The 2019 edition of their flagship publication, the China Renewable Energy Outlook was signed-off by the Director of the China National Renewable Energy Centre, who serves as the Acting Director of the Energy Research Institute of the NDRC. As reported in the document, the CNREC and ERI are the implementing units, with the financial support for CIFF, the Danish and the German governments, as well as the technical support of the Danish Energy Agency, GiZ, the German Energy Agency, the German organisation Agora Energiewende, EA Energy Analysis, and Danish grid company Energinet. Additional domestic support came from the Peking University, the State Grid Hebei Economic Research Institute and the North China Electric Power University (CNREC & ERI, 2019).

As explained by two interviewees, CNREC allows domestic and foreign experts to collaborate within a stable institutional setting. There is, however, a distinction between those Chinese experts that also hold a position as ERI researchers (like the Director himself), and foreign experts who are only part of CNREC (2A01, 2C10).

The relevance of CNREC planning was already mentioned in section 3.5. For foreign experts, planning allows the strengthening of political support for renewable energies. (2C07). Their contribution comes in the form of specific modelling tools and modellers like the Danish Balmorel tool (2A01)(CNREC & ERI, 2019). Local views favour the institutionalisation of a more centralised system of expansion planning, not only to support renewable target setting but also to optimise the transmission infrastructure development following the European example of ten-year statements to define specific infrastructure needs (2B01). In this regard, the German Energy Agency might provide particularly useful for regulators to access alternative voices and to develop capabilities for the design institutes (see DEA et al., 2019).

Other specific examples where policy advice has been provided include the design of flexibility mechanisms; and the design of spot markets (2C05, 2C07, 2C10). Their participation takes place in the context of collaboration with domestic knowledge holders. When the collaboration concerns specific pilots or implementation experiments at the regional or provincial level these happen in the context of partnerships, for example, with Xi'an Jiatong University (University of Communications of Xi'an) (2C05), the North China Electric Power University (2C06), Tsinghua University or EPPEI (2C09).

Interviewees were able to identify the historical or institutional logic of collaboration. Germany participated in the redesign of the compensation mechanism away from a feed-in-tariff is informed the German example. Similarly, the Danish grid company Energinet collaborated directly with State Grid. The US NREL had a long-standing relationship with the State Grid Energy Research Institute, while the US Orlando Berkeley National Energy Lab nurtured relations with the Southern China Grid for the implementation of their own market reforms (2C10, 2C07, 2C06, 2C09).

Some of the most important foreign actors participating in Mexico are similar to those in China, including the German GiZ, the Danish Energy Agency, Energienet, and NREL. Burt in addition to these actors, there is less diversity of foreign EOs compared to China. And in general, the relevance and impact of the foreign knowledge-holders appeared to be relatively less important in Mexico. Some actors like GiZ have been very effective in other areas of work, like energy efficiency, but have had less of an impact within the specific field of large-scale wind and solar integration.

There was a certain level of coincidence in the assessment communicated by both knowledge-holders and the government agencies regarding the relevance of existing relations. The less meaningful relations concerned SENER, despite their central position as policymakers. Next in order of relevance is the regulator CRE, which has had a long history of collaboration with foreign

knowledge-holders but whose position as a rule-maker has always been formally and politically undermined (1A04, 1A06, 1C06). Finally, the most significant relations were established with CENACE.

Following the argument already built in the previous two sections, this is related to the growing centrality of the system operators as convenor for the many areas of work for which they have been entrusted with authority. In some areas that are indisputably a concern of the system operator, CENACE has received the support of GiZ and Energienet. A very clear instance is over issues of forecasting of wind and solar generation. Mexico does not have regulation to penalise low quality forecasting from generators and will not consider it in the short term (1A01), and therefore requires the devising of a system to centrally improve the inputs for the real-time and day-ahead dispatch schedules (1A05, 1C06, 1C02, 1C08).

This subject is related to a much larger discussion about the need to develop markets for ancillary services and to adapt the grid code in such a way that wind and solar energy contribute more to grid stability and, therefore, experience less risk of being curtailed for technical reasons. These are both areas where GiZ (for solar) and DEA (for wind) have worked the most directly with CENACE. Or, on certain occasions, in collaboration with the private sector to provide evidence to both CENACE and the regulators (1C02, 1B05). The Grid Code remains a central subject where the three major cooperation programs attempt to continue working, including NREL, in addition to GiZ and DEA (1C06). There was no specific instance or evidence to specify a critical contribution. However, experts at CENACE reported being positively influenced by the learning during technical visits to the control centre of Energienet in Denmark.

The footprint for long-term planning was easier to trace. NREL has been active in Mexico as an implementing partner for the Children's Investment Fund Foundation, but also as a US government implementing agency. In both roles, it supported Mexico in the participation of the

regional North American Renewable Integration Study or NARIS (1C06, 1C03).[14] CENACE and INEEL participated in this initiative in collaboration with NREL modellers. In parallel, NREL provided support directly to SENER on the utilisation and improvement of the system Plexos (1C03). As explained before, the Plexos system modelling tool allowed SENER to refrain from using the tool originally used by CFE and developed by INEEL (under the name of PEGIT).[15] Finally, with the support of NREL, the country also developed a specific study on the electrical island of the southern portion of the Baja California peninsula in the Pacific (1A05). While the study did not seem to have an impact on decision making in the short term, it might have increased the capabilities of staff at CENACE.

In Mexico, there is only limited evidence that local knowledge-holders benefited or increased their capabilities based on the collaboration with foreign knowledge-holders (1C06, 1A03). Several interviewees reported a form of competition between domestic capabilities and foreign capabilities, with the INEEL model being displaced by commercial Plexos facilitated by NREL, or the National Polytechnic Institute (IPN) being side-lined by their former associate in holding the position of Independent Market Monitor (1C06, 1C10). However, there is also evidence that the initiatives specifically targeted to increase local capacities have been considered wasteful as there is a high rotation of personal and new tools are not utilised in regulation (2C09, 1C01). The Balmorel model, utilised by CNREC in China, was adapted by the National University (UNAM) with Danish support. However, shortly after implementation, the team disintegrated, and the scenarios have been used only in the development of long-term policy statements but have not informed policy decisions (1C01).[16]

[14] I participated as a consultant in this study for the development of the solar distributed generation model SAM during the summer of 2017 and remained an external advisor for the rest of the year. See https://www.nrel.gov/analysis/naris.html.

[15] CFE reportedly moved to Plexos under the new corporate structure but returned to PERGIT after finding it inappropriate for project evaluation purposes.

[16] This policy statement is called the Strategy on Transición to Promote the Use of Cleaner Technologies and Fuels (SENER, 2020).

Some foreign actors explicitly attempt to form integrated transnational knowledge networks, under the label of 'global learning approaches' (2C09, 2C10).[17] This was the case for the 21st Century Power Partnership originally launched during the US Barack Obama administration within the Clean Energy Ministerial. This initiative has formally clustered the work from expert organisations with public or private funding including, German DENA, Danish DEA, US NREL, and the UK-based CIFF. However, the level of integration of these actors is contrasted in the two countries. In China, these actors coalesce around CNREC, and particularly CIFF, DENA and DEA formally collaborate in detailed working programs as showcased by a periodic newsletter, the monthly "China Energy Policy Newsletter". This form of institutionalised collaboration between foreign knowledge holders and domestic actors is not evident in the Mexican case, where NREL serves as the implementing arm for CIFF with a certain level of coordination with the Danish Energy Agency. But in Mexico, these agencies do not have a local convener, as CNREC in China.

As the China Energy Policy Newsletter also shows it is also plausible to assume there is a high initial barrier to collaboration in the form of language and large institutional differences, which demand the use of a convenor role in the form of an institution like CNREC. This research, however, has limited depth to offer into this institutional divergence.

Foreign EOs do provide or produce valuable regulatory knowledge through transnational networks. This study shows that relations between a foreign expert organization and regulators are scarce and even when present might have a limited impact, unless in specific circumstances when regulators have a clear demand or requirement. However, when regulatory innovation depends on tacit knowledge of the local system a new technology, or both, their impact depends on the appropriate institutional nesting with other expert organisations locally or independent system operators. There is evidence that this additional layer to the regulatory ecosystem is particularly

[17] In fact, this research was triggered by the authors' experience in a number of activities of this particular form of transnational network, which brought new governance tools for renewable energy policymaking in a context of the structural weakness of the Ministry of Energy.

important for the development of governance tools that are relevant to renewable energy expansion, as they do bridge knowledge from jurisdictions with higher levels of wind or solar energy penetration and more appropriate market operations rules.

5.6 Conclusions: regulators strive for rebalancing

The evidence gathered for each case study supports the knowledge brokers hypothesis in general: Greater access to SOs and EOs, especially those in transnational networks, enables regulators to develop more innovative and effective regulatory solutions by increasing the provision of specialised knowledge. And the process analysis provided a more complex perspective on the interacting effects of different types of actors.

In both countries, the state-owned companies have preferential access to policymaking. The bottom-up recollection of their interests occurs through mechanisms like government officials taking board positions, as in the case of CFE in Mexico, or the existence of a bureaucratic actor entrusted with protecting the value of the companies, like SASAC in China. At the same time, state-owned companies might face the formal or informal obligation to align their strategy to fulfil economic objectives external to the immediate business of the company, like the expansion of provincial revenue bases in China, or expanding natural gas supply in Mexico.

"The State Grid is very powerful", said an interviewee "but not powerful enough to coordinate provincial governments" (2C08). Central regulators will not do better by themselves. Instead, a number of domestic and foreign expert organisations help central regulators re-balance the distribution of knowledge, resolve a problem of asymmetry, and push forward regional market integration.

The Mexican case shows a similar drive to enlist capable allies. The difference is that the government successfully appropriated the SO. Providing independence from the state utility, the Ministry gained the knowledge and implementation capacity of the most competent actor. This

has increased the capacity of the government to benefit from the knowledge provided by local and foreign expert organisations. The SO becomes a crucial component in new chains of knowledge brokerage.

The different ecosystems of the two countries show alternative institutional pathways to build regulatory capacity through appropriating, enlisting or creating allies with sufficient expertise and competence. State-ownership does not provide regulator with unencumbered access to asset-owner's knowledge, but neither are regulators imprisoned by the dominance of these incumbents. SOs and EOs that serve as knowledge brokers mitigate knowledge asymmetry and rebalance the power in favour of the regulators.

As it appears in this comparison, institutional choices are fraught with historical trade-offs and path-dependency. Mexico's system operator may have already become the most important, and virtually sole knowledge broker as it utilises the contribution of expert organisations, domestic and foreign. China's central regulators have nurtured a wider array of actors, enlisting or creating new actors. The latter were delegated relevant functions in the areas of planning, implementation of market reforms, and monitoring.

In Mexico, the independent SO takes over significant roles of rulemaking, rules implementation, planning and supervision. In this position, the system operator centralises knowledge production and provision to regulators. Domestic and foreign EOs are most effective when collaborating with the SO as both an intermediary to regulators and a de facto regulator. In China, various specialised research centres are entrusted with regulatory responsibilities and serve as intermediaries of knowledge. Hence, parallel paths of intermediation follow bureaucratic fragmentation.

Domestic EOs, but particularly foreign EO, require nesting and close relations with a local intermediary. In Mexico, expert organisations are most effective when working with the system operator. In China, this happens primarily through the China National Renewable Energy Centre, but increasingly EPPEI and research universities like the North China Electric Power University.

In light of the Chinese case, Mexico has a weak ecosystem of local expert organisations to interact with foreign expert organisations. The relevance of the system operator reinforces this as the most effective actor to broker learning from experts in transnational networks.

6 Conclusions

Knowledge brokers increase the regulatory capability in the ecosystem, reduce the asymmetry between regulators and asset-owners, and contribute to the development of governance innovations. These claims go beyond the mere statement that the provision of knowledge by SOs and EOs is important. In this research I uncover multiple instances in which effective governance is underpinned by the participation of highly knowledgeable organizations. However, this research shows that the relevance of any particular EO or SO depends on the specific circumstances of knowledge scarcity, and the relative importance of tacit knowledge in the governance and evolution of the electricity system.

With the data available in 2018, a working hypothesis was that countries with no independent system operator would have more challenges to expand the share of wind and solar energy, or that their expansion would entail larger costs to consumers or fiscal budgets. In early 2021, the UK regulator, Ofgem, finally recommended the full unbundling and independence of the system operator with full capabilities to coordinate investment in grid infrastructure, plan with a whole system perspective and develop new markets. Ofgem reports plausible savings up to 4.8 billion pounds in the next three decades, at almost no additional cost to consumers (Ofgem, 2021). While this decision by Ofgem correspond to the assumptions and findings of this thesis on the significance of a public independent SO, the comparative research could not establish that there is a unique institutional configuration for renewable energy deployment success, to a large extent given the lack of sufficient contrast in the outcomes between the sample of countries, as described in chapter 2. However, the patterns across cases do provide an empirical basis to

develop a research program of the governance of the electricity system beyond classical regulatory studies.

Regulators engage in extensive knowledge exchange beyond the asset-owners they regulate. This results from regulators' demand for the knowledge held by SOs and EOs. However, the supply is not naturally available but historically dependent on political evolution of the regulatory ecosystem, for example, through providing independence to SOs or creating new EOs with a mission to produce regulatory knowledge. This historical evolution is path-dependent and may not be intentionally guided to foster a richer knowledge environment. For example, the main goal to increase the independence of SOs is to guaranteeing fair access to grid interconnection and avoid a grid company conflict of interest. But an important consequence is a meaningful redistribution of knowledge and, therefore, political power. Similarly, contracts with Universities to produce certain planning reports or tools have capacity building effects that go beyond the length of the contract and can potentially redefine the landscape of knowledge distribution.

This thesis advances a call to understand regulatory capacity from a system perspective, not as an attribute of a specific public agency, but as a latent feature of the ecosystem. Regulators are embedded in networks of non-asset owning actors which they actively shape. In the UK, the extensive network of EOs working with the industry, trade association and regulators thrives thanks to the existence of regulated allowances for research and direct public funding. But the single most significant tool in reshaping the ecosystem of knowledge exchange is the provision of independence to the system operator, as in the cases of Chile and Mexico.

The concluding chapter provides a summary of research findings and the implications to the study of technological change and policy making for decarbonisation. This research project leverages in-depth case analysis to understand the mechanisms of knowledge exchange and brokerage in different contexts. The research makes contributions at three different levels: firstly, empirical descriptions of regulatory ecosystems and regulatory outcomes; secondly, the

characterisation of the mechanism of knowledge exchange and brokerage; and ultimately, to test the causal depth of the knowledge broker hypothesis.

6.1 Finding of emerging patterns of knowledge brokerage

This thesis provides evidence to argue that greater access to system operators (SOs) and expert organisations (EO) enables regulators to develop more innovative and effective regulatory solutions by increasing the provision of specialised knowledge. Moreover, it provides evidence of how crucial independent SOs are to the rapid deployment of new governance tools that favour renewable energy, although there is also evidence that outright independence of the SO is not a necessary condition for success. Rather, the analysis shows that a robust network of EOs can serve as a relative substitute to moderate and overcome regulatory knowledge gaps.

Regulators in liberal markets, the UK and Chile, hold tools to build redundant paths for knowledge access. This means that they actively nurture the presence of multiple EOs and, in the case of UK, multiple SO-like organizations. In the UK, a great variety of asset-owners can partner with the multiple EOs that compete for research funding. Furthermore, the UK has created new EOs like the Climate Change Commission and The Catapult to more effectively utilise and combine local EOs expertise. While Chile has a less rich ecosystem, domestic EOs are still a constant in regulatory processes that have been fundamental for renewable energy integration. For the case of Chile, the patterns of interaction resemble those of the UK. The most evident example is the University of Chile and other local EOs are contracted by the government. Their role is widely regarded as critical in areas like system planning. And while there is commercial software and widespread expertise on its use, the role of software development and the tacit knowledge about the characteristics of the local grid are critical to delivering useful products at the right moment. In Chile, the negative to create a central Institute of Energy is yet another point that evidence a preference for parallel paths of intermediation.

In Chile, crucial evidence of the desire to nurture redundancy in Chile, is the lack of support for the create of an Institute of Energy which would centralise research for regulatory purposes.

Even the difference between the UK and Chile regarding the organisation of SO functions speaks to the affinity between market regimes and the search for redundancy in knowledge sources. In cases where the choice is to keep SO functions as much as possible within the remit of the asset-owner while ensuring they fulfil public goals —as in the UK— SO roles are fragmented through multiple actors with specific mandates, like Elexon or the Low Carbon Contract Company, as independent bodies from the National Grid of the Ministry.

In state-dominated markets the challenge of asymmetry of knowledge is equally relevant. State-owned companies –whose interests are not necessarily aligned with those of regulators– have privileged access to policy making. The evolution of the ecosystem of knowledge brokerage results from splitting incumbents, empowering domestic EOs and leveraging the knowledge of foreign EOs. These are all paths to ameliorate the potential negative consequences of state-owned enterprise dominance.

China's rebalancing is clear even if not highly visible. China delegates certain roles of market implementation at the provincial level to a selected number of universities and research institutes and empower engineering and design institutes through the creation of new centres with specific regulatory functions. In Mexico the rebalancing was more visible. The unbundling of the SO represented a major shift in the distribution of knowledge as a resource, in addition to the main stated policy goals of unbundling: fair interconnection and market operation for new private developers. But along with the independence of the SO, in the Mexican case we see other EOs played a relevant role in the implementation of market reform and the development of new governance instruments, including auctions.

A common feature in the cases dominated by state-owned companies is the crucial role played by public EOs that have a longstanding relation to the central regulators. The engineering and

design institutes in China and the Institute for Electricity and Clean Energy in Mexico have mandates to work on applied research and have been delegated or contracted to perform permanent regulatory functions that other EOs, such as Universities, do not. This has meant that the rebalancing of power away from the state-owned enterprises does not only happen through the empowering of private asset-owners or independent regulatory agencies, but through other types of state-owned institutions.

These are valuable insights and opportunities to generalise patterns beyond models of liberalisation. Chile and Mexico made their SOs independent from asset-owners and transformed them into public agencies. This was a re-concentration of authority and a valuable avenue for brokerage. This structural similarity creates patterns of interaction across the entire regulatory ecology. In both cases the independent SO concentrates significant attention and commands the collaboration with domestic and foreign EOs. Simultaneously, this has also meant that relations between the independent SO and EOs become more important, while the relationship between EOs and regulators diminishes in significance. In Mexico, the Institute for Electricity and Clean Energy was rapidly side-lined by the Ministry of Energy, despite its historic role in the development planning instruments and the implementation of new market rules into operation software. The institute remained in the regulatory loop only because of their work with the SO.

The two countries with no independent SO, the UK and China, show a relatively more diverse and robust ecosystem of EOs and even a growing number of SO-like organisations. In this context, EOs collaborate directly with regulators in designated environments where EOs and asset-owners work on specific regulatory innovations. This is the case of market implementation initiatives in both China and the UK, where central regulators demand EOs' involvement in processes of system operation innovations. This happened through regulatory mandates for asset-owners to partner with EOs in the UK, and mandates for provincial government and local grid operators to partner with EOs in China.

The similarities in the two pairwise comparisons provide evidence that the independence of SOs and the strength of an EOs ecosystem are historical substitutes. With no independent SO, the involvement of EOs is more consequential. This does not mean that regulators make a conscious choice between them, but rather, that in the absence of an independent SO there is a vacuum where EOs have a latent opportunity for influence. Similarly, the presence of an independent SO reduces the knowledge asymmetry and the potential role or impact of EOs. This substitution effect leads to an important discussion on the conditions that reduce the individual importance of any particular actors and on the dynamic characteristic of the regulatory ecosystem.

This research makes a particular contribution to the Chinese experience with curtailment, from the very high levels of mid-2010s to the precipitous drop between 2019 and 2020. The theoretical and methodological proposal in this thesis can provide an explanation to the successful management of curtailment. Scholars have tentatively pointed to the introduction of flexibility mechanisms to compensate thermal power plants being dispatched down and the adoption of central government targets for the grid companies. Scholars have focused on regulatory innovations because there has not been any significant change to the structure of the regulators or the industry. These explanations have omitted the significance of EOs in fulfilling market design and monitoring roles that are part of the regulatory process. For example, there is little if any mention of the China Northern Electric Power University or other EOs in the implementation of flexibility markets, or the National Renewable Energy Consumption Monitoring and Early Warning Centre to monitor compliance with curtailment targets. A careful process analysis would show these actors to be present at critical inflexion points and that creating and delegating roles to EOs is a form of regulatory reform even if no independent regulatory agency is involved.

6.2 Knowledge ecosystems without brokers

When knowledge is no longer scarce, or widely distributed, there is no position of a broker. The empirical research shows that ecosystems can develop sufficient alternatives path for knowledge, and that that multiple actors can compete to provide expertise to the regulators. In these conditions it might already be inappropriate to talk about knowledge brokers, as knowledge is no longer scarce or concentrated.

In the UK, for instance, a rich ecosystem of EOs means that no one is clearly more of a broker than others. In these circumstances, EOs behave as though working within a marketplace for knowledge. When I asked a senior member of ES Catapult about the complementarity between their energy products and those of institutions like Imperial College, he tentatively explained that their models are more like competitors (3C02). And this can be said also of the work done by the National Grid ESO on the Future Energy Scenarios, which other actors, including Ofgem and the National Grid headquarters do not consider the authoritative reference, but just another informed view of the future.

This research shows two political worlds that offer alternatives to the ideal of an administrative state of all-knowing agencies and the disparaging view of the structural regulatory weakness due to the asymmetric position of asset-owners. I describe one political world as an ecosystem where the regulators are highly dependent on knowledge brokers. The second has also an ecosystem perspective, where intermediation is crucial but abundant. In this second world, there are no specific actors with a prominent position as a knowledge intermediator. There are SOs and EOs, but none are knowledge brokers. More precisely, the second world is the result of three different interacting conditions: crucial tacit knowledge is codified and explicit; this knowledge is widely diffused amongst many comparable actors, and regulators do not delegate any power to EOs.

These findings go beyond my research expectations; however, they strengthen the theoretical proposal to describe regulatory capacity as an ecosystem attribute. At the same time, they

provide a framework to define the scope conditions in which knowledge holders become brokers.

Knowledge brokerage depends on the existence of a knowledge gap. When the tacit nature of relevant knowledge and the uncertainty of a changing technological frontier increases, so does the need for knowledge brokerage. Similarly, deployment of technologies leads to the codification and diffusion of knowledge, especially on the interaction between new technologies and the existing systems, which have proved to be a challenging intersection distinct area of tacit knowledge.

This process of codification accelerates the diffusion of knowledge and the multiplication of actors able to provide such knowledge. In circumstances where many actors occupy a similar standing to provide regulators with knowledge, no single actor can be considered a broker. Regulators can access knowledge through multiple paths reducing the importance of any particular actor. This means that the greater the density of relations within the regulatory ecology, the more it resembles a market for knowledge rather than a network with discrete meaningful relations. The UK is the clearest example, but even in China there is a growing number of institutions that provide support for market implementation; a roster of pre-selected universities and engineering institutions and a number of foreign EOs, NGOs and consultancies that support provincial processes of market design reform. These EOs in China are a cornerstone of regulatory governance, but each particular EO —domestic or foreign— increasingly loses individual importance.

Regulators can actively foster the existence of a multitude of effective knowledge providers. In the UK, the Pathfinders project from the National Grid ESO provides a good example of a framework for experimentation and rapid codification. The Pathfinder process is a market product creation process that is directly managed by the SO, rather than the regulators. In Mexico, interviewees reported the deployment of large-scale batteries driven by very intense

coordination between the battery owners and the system operator, with the expectation that the successful operation of the first batteries in Baja California Sur would lead to the standardisation of operational procedures and its integration into future system planning with the support of GiZ.

A different reason for the absence of knowledge brokers is that regulators prefer not to delegate authority to these potential knowledge brokers. This is the case when SOs lack independence and the regulator provides limited mandates due to the risk of undue influence from the grid companies. It is also the case for regulators that do not rely on EOs during the regulatory process. EOs relevance depends not merely on competence but on delegation of regulatory roles.

The historical evidence and interviews clearly show that in many instances, EOs develop competence and acquire tacit knowledge at certain points in time precisely because they have been invested in completing a task requested by the regulator. Their tacit knowledge is thus a capital that diminishes with time but can be maintained through continuous engagement in delivering knowledge-based products to the regulators. In Mexico, signs of deterioration of the EO role in brokerage were already evident, as INEEL systems planning contracts with the Ministry and the state-owned utility were rescinded. This might happen even under the best government intentions. In Chile, the creation of a planning department at the Ministry of Energy with former members from the Universidad de Chile might result in a loss of relative importance for the university. This is also a reason why foreign EOs require nesting within domestic EOs or the SO. The transnational network formed around the China Renewable Energy Centre is an example of a chain of brokerage where foreign EOs' contribution is determined by their collaboration with a domestic EO.

6.3 Policy implications

This research provides evidence relevant to the politics and policy of electricity system governance reforms in favour of decarbonisation. Three specific recommendations derive from the analysis in this research:

1. Build regulatory ecosystems (not merely agencies) and empower knowledge brokers.
2. Leverage and invest in the competence of intermediaries in governance reforms.
3. Embed international collaboration within appropriate local intermediaries.

Public authorities have the capacity to create a favourable environment for regulation by utilising means of indirect governance. In fact, public authorities can shape the capabilities of EOs through delegating regulatory roles and contracting the production of key knowledge products. During the interviews, I commonly referred to 'knowledge exchange'. A system operator engineer interjected with a suggestion: "Co-production is a more appropriate word" to refer to the relations between the SO, EOs and the asset-owners (1A05). The clarification from the interviewee refers to the need to differentiate producing from merely providing knowledge. The relationship between INEEL and CENACE in Mexico and between the DEA and CNREC in China could be designated as co-production. These expert organisations engage in the joint development of regulatory tools, like crafting planning software or adapting existing operational protocols to the local context. Co-production also denotes a specific type of motivation, a problem-driven process of knowledge generation. This is relevant to explain the significance of formal delegation of regulatory roles. SOs and EOs are entrusted to fulfil a regulatory role with the aim of tackling new problems and, in response, they produce new knowledge. This is a stronger regulatory ecosystem than one where only asset-owners provide input for regulatory decisions.

This recommendation contrast with the standard recommendations of liberalisation reforms, which focus on establishing an independent regulatory agency for market competition. This

research recommendation emphasizes the need for authorities to actively build an ecosystem of knowledge providers as a fundamental component of a functional regulatory environment. Furthermore, some literature has stressed the need to undermine the dominance of state-owned enterprises over the political process through privatisation and fragmentation of their assets. This research shows an alternative avenue, to create and nurture a public SO independent from asset-owners or well-funded EOs with delegated authorities that support decision making by regulators. In practice, empowering knowledge brokers would be politically more feasible than directly capping the political influence of dominant asset-owners through utility restructuring.

For the last four decades governance reforms in the electricity sector have referred mostly to the liberalisation of electricity markets. Only recently are they moving towards re-regulation and increased political control over the sector. The creation of the Ministry of Energy in Chile or the state-owned Low Carbon Contract Company in the UK are examples of historical reckoning. The revisionism over liberalisation opens a window of opportunity to recognise electricity system governance as embedded within a wider network of actors beyond the regulator, the asset-owners and consumers. Initiatives of reform must account for the weakness and strengths in this wider ecosystem. Where EOs are scarce or have developed little influence due to the pre-eminence of private or state asset-owners in governance, reformers must invest in the competence of intermediaries, which might be crucial to the deployment of reform and the designing of new market instruments. Where EOs are abundant and actively engaged in regulatory knowledge production, reformers must acknowledge their significance. Not doing so might hinder our understanding of the conditions that explain success. Mexico Ministry of Energy cancelling their collaboration with the local state research institute undermines the long-term regulatory capacity of the country, just as increased delegation to EOs in the UK, Chile and China enhances it.

The move to create independent system operators in Mexico and Chile and increasing autonomy in the UK and China are also largely omitted from political discussions despite being highly consequential in the rebalancing of regulatory power. Omitting the role of intermediaries makes for a poor account of institutional evolution. As Mexico approved the new legal framework for opening markets and created an ISO, China dismantled the State Electricity Regulatory Commission and has not yet integrated the SO into an organisation dependent on the National Energy Agency. This is a stark institutional contrast. However, a closer look provides evidence of parallelisms of institutional and regulatory innovation, beyond the mere protection of competition, towards the central management of multiple overlapping markets with different rules. This evolution helps explain the implementation of new market devices like electricity auctions in Mexico and flexibility markets in China. Competition as a regulatory mechanism loses relevance, while there is a growing reliance on engineering-based institutions for the implementation of the new compensation and contracting instruments.

Finally, regulators seeking to benefit from the support and competence of foreign EOs should create the conditions for nesting these foreign organisations, enabling them to work with local EOs and the independent SO if there is one. This is an insight from the comparison between China and Mexico, where foreign EOs are productively nested within CNREC in China but have had much less impact in Mexico, as they attempt to support regulators that might not be sufficiently competent, or too far removed from the operation of the industry to benefit from foreign EOs potential contributions. The missed opportunities from inappropriate nesting of foreign EOs in Mexico became more evident after the 2019 change of policy when the Ministry of Energy stopped everyday collaboration with foreign EOs, but not with local EOs nor the SO.

The prominence of the German government agencies in Mexico, China and Chile, and those of Denmark in Mexico and China, speak to the relative importance of technical cooperation implemented by organisations with high expertise directly, rather than other models driven by

consultant work, such that of the US, UK or even developing banks like the World Bank or regional banks, all of which appear less prominently or not at all in the empirical research. This explains why even within the US based cooperation ecosystem, the work of NREL funded by the private donor CIFF, is generally more prominent than any other specific instance of cooperation. GiZ, Energienet, NREL, and other actors with technical expertise can establish deeper and more durable relations with local actors and, through them, have a more significant impact. This is explained by the opportunity to combine tacit knowledge about new technologies, like solar and wind generation forecasting or battery storage, with tacit knowledge about the local grid.

These recommendations are consistent with an understanding of the benefits of embedding the exercise of regulation within an appropriate ecosystem of supporting institutions. They also highlight the importance of avoiding presumptions that formal institutional reforms are sufficient to effectively transform the politics governing electricity decarbonisation, against the preference of asset-owners invested in fossil fuel technologies.

6.4 The future of electricity systems governance

Government control over the industry is on the rise, even in state-dominated electricity systems, but not through classical forms of concentration of power in a political actor. Rather, the changes point to a decentralisation of decision making in political authorities embedded within richer networks of competent organisations that supply useful knowledge for their decisions. In this sense, delegating regulatory work to more competent organisations can reinforce the power of the state.

There are important caveats to this statement which speak to a more classical political economy understanding of regulatory relations. The recent book *Short circuiting policy* by Leah Strokes (2020) shows with precision the multiple ways in which dominant utilities are able to block

policies that favour renewable expansion, usually under the clout of technical inscrutability, in the open policy debates in legislatures and regulators offices. In 2020, the US federal authorities uncovered a corruption circuit to bootstrap a bailout for the incumbent utility in the state of Ohio. The investigation proved that the leader of the state legislature had received benefits in exchange of legislative action to erode the conditions for independent renewable energy producers, and to provide a bailout to the fossil fuel and nuclear thermal power plant fleet of the utility (E. Wolff, 2020). The delegation of regulatory choices to EOs and independent SOs might have moderated the effect of the political decision. The purpose of corruption was to bypass all consideration of alternative opinions about requirements for the health of the local electricity industry.

Not only do asset-owners capture regulators, but they also capture intermediaries. This poses a different type of regulatory capture risk. Karthik Ramanna describes 'thin political markets' where regulation depends on few specialists with strong economic interest in the outcome and the process of capture extends to actors that could serve as counterweight (Ramanna, 2015, p. xix). This is yet another reason to place knowledge brokers front and centre in public debates, because the public need to know who is advising the government in the decisions they are taking. And this technical advice role becomes more important as economies move towards managed markets through the use of instruments like auctions.

In 2020, the central bank of Sweden awarded its Prize in Economic Science to Robert P. Wilson and Paul Milgrom for their work on auction theory and the invention of new auction formats. The award was applauded by practitioners in electricity market design. After all, the most lauded regulatory innovation in the 2010s was the expansion of renewable energy auctions. It also shed light on the relevance of competencies in the fields of engineering and computation that might be beyond that of regulators trained in economics and law. However, it also re-opened existing

debates about conflicts of interest around Milgrom's activities as an auction design consultant for telecommunications authorities (see Feltri, 2020; Weyl, 2020).

The Milgrom-as-consultant controversy speaks to the fact that regulators' reliance on external sources of knowledge does not necessarily annul the problem of capture, but rather displaces the location and range of capture. Following this argument, there is a need to rethink the description of the electricity industry less from the perspective of industrial economies and more from the perspective of political communities, with innate conflicts of power. We need to consider increasing the capability of public institutions to leverage the presence of many other expert organisations whose missions coincide with a public goal. Scholars can contribute to such institutional evolution by focusing on how these intermediaries develop public power.

As regulators in electricity turn towards market instrument (ie. auctions) design as a governance tactic, market outcomes will be predetermined to a large extent. Regulators will be required to decide how much implementation will be done in house or delegated and to whom. Who runs the auction? Who forecasts flexibility services demand? Who defines the re-dispatching at distribution level? With a turbulent future, shaped by high political pressure and rapid technological change, the future of a strong regulatory environment is accurately defined by this statement from a senior engineer at Chile's ISO: "more eyes, but fewer vetoes". Thus, more delegated power to those actors that are more accountable to public authorities and the public, and less reliance on asset-owners as the sole provider of expertise, not only for the sake of improving implementation in the present, but to build stronger regulatory ecosystems for future challenges.

Enabling, enlisting or creating knowledge brokers should be seen as a political means rather than a goal. The goal is ecosystem capacity, and knowledge brokers appear as transitory between a moment of expanding knowledge gaps and a moment where many actors have command over the necessary knowledge to make better decisions. The success of any particular knowledge

broker should result in its demise as a powerful knowledge holder. That said, we can expect decades of rapid change in energy systems propelled by even more ambitious targets for decarbonisation. This means the continuous emergence of new technological and institutional problems creating knowledge gaps that call for more instances of knowledge brokerage.

6.5 Politics and knowledge brokerage beyond electricity

Observing the effective or latent importance of knowledge brokers requires a political understanding of regulatory relations. This understanding does not merely emphasise conflict and power asymmetries between politicians, regulators and asset-owners; it uncovers power resulting from coordinated action between regulators and a wider array of actors. Mary Parker Follett described the access to and development of power as *power-with*, power not as an attribute of the actors but of the process in which interaction, difference, and collaboration take place (Follett, 1924, p. 187).

This research aims to place front and centre an understanding of state power as dependent on socio-political embedding, and in the particular case of technological change, on the evolution of relations between expert organisations and other industrial actors that can embrace a public purpose rather than those of an asset-owner.

This is not only a subject worth considering in the electricity sector. Other sectors have seen steep trends of technological change that require significant regulatory intervention. Two particular instances are in the fields of finance and cyber security.

The broad field of finance provides the first example of a sector that hinges on regulatory decision for its existence in contemporary economies, and where the role of the expertise of non-asset owners must be well understood. Karthik Ramanna's (2015) work on accounting standards show the daunting challenge of regulatory work in a field that is usually far removed from the public eye and debate. In this field the presence of certain intermediaries can become

fundamental, as in the case of accounting boards and associations that set standards for the industry. In the subfield of banking, regulators have a prominent ally, central banks, so much that they have been delegated with regulatory responsibilities beyond monetary management. In some jurisdictions, like in the UK, the central banks go further to implement regulation over other critical sectors like the insurance and reinsurance industries. Central banks are power allies and source of competence to govern both private and state-owned banking institutions. But even this field emerging, highly technical problem, require for expanding the ecosystem of expert organisation and networks of transnational collaboration, as evidenced by the work of the Network of Greening the Financial System to develop tools that central bankers can use to engage in regulating climate-related financial risk (NGSF, 2020).

Digital services and cyber security are another field where research and policy will benefit from recognising the role of knowledge brokers in a regulatory capacity. In contrast to the focus on consumer and privacy protection in advanced economies, a more widespread concern is cyber security. Most governments in developing economies have a very serious gap of competence in this field because of the lack of a domestic industry. Carlos Solar (2020) shows that in these circumstances governments have increasingly relied on the only domestic actor that invest in building internal digital security capabilities: the military. According to Solar's research in the case of Latin America the relevance of the military is partially explained by the existence of networks of security cooperation with the United States military. Regulators must find external sources of competence that are different from the asset-owners in the industry, all of them private and in most cases entirely foreign. The local military, with the support of transnational networks created by the US military, have filled that regulatory knowledge gap.

The opportunity to strengthen regulatory capacity is also relevant beyond the sovereign state. This includes global governance in fields like climate change, biodiversity and the health of the oceans, which can be directly subjected to international law and regulation. Institutional forms

like the Intergovernmental Panel on Climate Change and specific networks of collaboration between private and public actors, inform international policy markets and government coalitions in meaningful ways.

The knowledge brokerage discussed throughout this text speaks to an idea of the politics of economic governance that transcends the scope of economic interests, by introducing a wider set of actors with a mission or objective that is not defined by the market in question. These actors are not stakeholders in the regulatory sense but might either embody a public purpose because they were created by the state or because they are institutional carriers of a public mission, like Universities. Thus, this research findings are also a call to widen the polity that governs the economy, and to look for them beyond the market.

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Appendix 1. Acronyms and names in original language

A1.1 Acronyms shared by more than one country

Acronym / Short name	Name
CIFF	The Children's Investment Fund Foundation
DEA	Danish Energy Agency
NREL	National Renewable Energy Lab
DTU (DK)	Danish Technical University
Energinet	ESTA International (Consultancy)
GiZ (DE)	German Cooperation for Development Agency
WWF	World Wildlife Fund

A1.4 Acronyms for Chile

Acronym	Name	Name used in Spanish
50HRZ	50HRZ	50HRZ
ACERA AG	Chilenian Association of Renewable energy	Asociación Chilena de Energías Renovables Asociación Gremial
Avina	Avina (NGO)	Avina (ONG)
CAF	Andean Promotion Corporation	Corporación Andina de Fomento
CCME	Cientific Committe for Mitigation and Energy	Comité Científico de Mitigación y Energía
Chile Sustentable	Chile Sustentable (NGO)	Chile Sustentable (ONG)
CIGRE	International Council on Large Electric Systems	Consejo Internacional de Grandes Sistemas Eléctricos

CNE	National Energy Commission	Comisión Nacional de Energía
Congress	Congress (center-left alliance)	Congreso
Consultants	Consultants	Consultores internacionales
Coordinador	Coordinador Eléctrico	Coordinador Eléctrico
Corfo	Corporación de Fomento	Corporación de Comento
DoE	USA Department of Energy	Departamento de Energía de Estados Unidos
E.E. AG	Energy Companies (trade association)	Empresas Elétricas Asociación Gremial
FIMA (NGO)	Environmental Prosecutor (NGO)	Fiscalía del Medio Ambiente (ONG)
Generadoras AG	Generadoras AG (trade association)	Generadoras AG
GiZ	German Development Cooperation program	Agencia de Cooperación para el Desarrollo Alemana
Greenpeace	Greenpeace	Greenpeace
IADB	Inter-American Development Bank	Banco Interamericano de Desarrollo
Local consultants	Local consultants	Consultores locales
Ministry of Energy	Ministry of Energy	Ministerio de Energía
Ministry of Environment	Ministry of Environment	Ministerio de Medio Ambiente
Ministry of Finance	Ministry of Finance	Ministerio de Finanzas
Ministry of Transportation	Ministry of Transportation	Ministerio del Transporte
Panel	Expert Panel	Panel de Expertos
Private companies	Private companies	Compañías privadas
PUC	Pontifical University of Chile	Pontificia Universidad de Chile
SEC	Energy and Fuels Controller	Superintendiencia de Electricidad y Combustibles
SwitzerlandGov	Switzerland Government	Gobierno de Suiza
Transelec	Transelec	Transelec
UC	Energy Centre - University of Chile	Centro de Energía, Universidad de Chile
UC Denver	University of Colorado Denver	Universidad de Colorado, Denver

A1.1 Acronyms for UK

Acronym / Short name	Name
Arup	Arup
BEIS	Ministry of Business, Energy & Industrial Strategy
Birmingham	University of Birmingham
BNEF	Bloomberg New Energy Finance
Cambridge	University of Cambridge
Carbon Trust	The Carbon Trust
CCC	Climate Change Commission
Citizens Advise	Citizens Advise
CREA	Chiena Renewable Energy Association
Crown Estates	Crown Estates
DEFRA	Departmetn of Enviornment, Food & Rural Affairs
Devolved Gov	Devolved Governments (essentially Scottish Gov)
DNOs	Distribution Network Operators
Durham	University of Durham
E3G	E3G
EDF	EDF
Elexon	Elexon
ENA	Energy Networks Association
Energy UK	Energy UK
Entrepreneur	Entrepreneur
ES Catapult	Energy Systems Catapult
ETC	Energy Transition Commission
Euroelectric	Euroelectric

Eurogas	Eurogas
Greenpeace	Greenpeace
HVDC Centre	The National HVDC Centre
IEA	International Energy Agency
Imperial	Imperial College
Infraestructure Commission	Infraestructure Commission
Innovate UK	Innovate UK
JRC	Joint Radio Company
LCCC	Low Carbon Contract Company
Local governments	Local governments
MAA/CAA	Military Aviation Authority and Civil Aviation Authority
Manchester	University of Manchester
National Grid	National Grid
New Castle	University of New Castle
NG ESO	National Grid ESO
NG USA	National Grid USA subsidiaries
Ofgem	Ofgem
ORE Catapult	Offshore Renewable Energy Catapult
Oxford	Oxford University
Private Consultancies	Private Consultancies
Renewables UK	Renewables UK
Ricardo Energy	Ricardo Energy
RTE	RTE (France)
Scottish Power	Scottish Power
Smith Institute	Smith Institute
Strathclyde	University of Strathclyde

Names in English commonly used are not necessarily direct translations from Chinese language. In some instances where the English name refers to Renewable Energy, the actual translation would be "hydropower" or "new energy". However, I utilise the translation as observed in available documents or interview conversations.

A1.4 Acronyms for China

Acronym	Name	Name in Chinese	Chinese short name	Parent
NDRC	National Development and Reform Commission	国家发张哥改革委员会	发改委	State Council
NEA	National Energy Administration of China	国家能源局	能源局	State Council
CMRI	China Macroeconomic Research Institute	中国宏观经济研究院	宏观研究院	NDRC
ERI	Energy Research Institute	能源研究所	能源研究所	NDRC
CNREC	China National Renewable Energy Center	国家可再生能源中心	可再生能源中心	ERI
CREEI	China Renewable Energy Engineering Institute	水电水利规划设计总院	水规院	NEA
CREIC	National Renewable Energy Information Centre	国家可再生能源信息管理中心		CREEI
EPPEI	Electric Power Planning and Engineering Institute	电力规划设计总院	电规总院	NEA
	National New Energy Power Planning and Engineering Institute	全国新能电力规划设计总院		EPPEI /NEA
	National Power Planning, Monitoring and Early Warning Centre	全国电力规划实施监测预测中心		EPPEI /NEA
CREMC	National Renewable Energy Consumption Monitoring and Early Warning Center	全国新能源消纳监测预警中心		EPPEI /NEA
DRC	Development Research Center of the State Council	国务院发展研究中心	国务院发展研究中心	State Council
State Grid	State Grid Corporation of China	国家电网公司	国网	
SGERI	State Grid Energy Research Institute Co. Ltd.	国网能源研究院有限公司	国网能研院	State Grid
CEPRI	China Electric Power Research Institute	中国电力科学研究院有限公司	中国电科院	State Grid
SPERI	State Grid Economic and Technology Research Institute	国网北京经济技术研究院		State Grid
NCEPU	North China Electric Power University	华北电力大学	华北	
Tsinghua	Tsinghua University	清华大学	清华	

Acronym	Name	Name in Chinese	Chinese short name	Parent
CEC	China Electricity Council	中国电力企业联合会	中电联	
CREIA	Chinese Renewable Energy Industries Association	中国能源研究会可再生能源专业委员会	再生能源会	
RAP	Regulatory Assistance Project	睿博能源智库		
EF	Energy Foundation China	能源基金会		
NRDC	National Resource Defense Council	自然资源保护协会		

A1.5 Acronyms for Mexico

Acronym	Name	Name used in Spanish
Agora (DE)	Agora Energiewende	Agora
AMDEE	Mexican Wind Energy Association	Asociación Mexicana de Energía Eólica
ANES	National Solar Energy Association	Asociación Nacional de Energía Solar
ASOLMEX	ASOLMEX (solar energy association)	Asoiación Mexicana de Energía Solar
CANAME	National Chamber of Electrical Equipment	Camara Nacional de Manufacturas Eléctricas
CENACE	National Energy Control Centre	Centro Nacional de Control de Energía
CENAGAS	National Center for Gas	Centro Nacional de Control de Gas
CENAM	National Centre for Normalization	Centro Nacional de Metrología
CESPEDES	Centre for Economic Studies of the Private Sector	Centro de Estudios del Sector Privado para el Desarrollo Sustentable
CFE_Corp	CFE Corporate	Comisión Federal de Electricidad- Corporativo
CFE_Geo	CFE Geothermal unit	Comisión Federal de Electricidad- Geotermia
CFE_Dist	CFE Distribution	Comisión Federal de Electricidad- Distribución
CFE_Gen	CFE Generation	Comisión Federal de Electricidad- Generación (7)
CFE_Trans	CFE Transmission	Comisión Federal de Electricidad- Tranmisión
CIDE	Centre for Research and Teaching in Economics	Centro de Investigación y Docencia Económica
CRE	Energy Regulatory Commission	Comisión Reguladora de Energía
ESTA	ESTA International (Consultancy)	
IADB	Inter-American Development Bank	Banco Interamericano de Desarrollo

Acronym	Name	Name used in Spanish
Iberdrola	Iberdrola	
ICM	Mexican Climate Initative	Iniciativa Climática Mexicana
IER-UNAM	Renewable Energy Institute-UNAM	Instituto de Energías Renovables
IFC	International Finance Corporation	Corporación Financiera Internacional
INEEL	National Institute for Electricity and Clean Energy	Instituto Nacional de Electricidad y Energías Limpias
IPN	National Polytechnic Institute	Instituto Politécnico Nacional
IMCO	Mexican Institute for Competitiveness	Instituto Mexicano para la Competitividad
MIM	Independent Market Monitor	Monitor Independiente del Mercado Eléctrico
NARUC	National Association of Regulatory Utility Commissioners	
NERC	North Electricity Reliability Council	
SEMARNAT	Ministry of Environment and Natural Resources	Secretaría de Medio Ambiente y Recursos Naturales
SENER	Ministry of Energy	Secretaría de Energía
SMN	National Meteorológic Service	Servicio Meteorológico Nacional
UMSNH	University of Michoacan	Universidad Michoacana de San Nicolas Hidalgo
UNAM	National Autonomous University of Mexico	Universidad Nacional Autónoma de México
Utility Est	Utility Est	
WRI	World Resource Institute	
Private_Gen	Key Private Generation Company	
Vestas	Vestas	
Ombudsman	Ombudsman de Energía (NGO)	Ombudsman de Energía (NGO)
PwC	PwC	
SHCP	Ministry of Finance	Secretaría de Hacienda y Crédito Público
USAID	US Agency for International Development	
WECC	Western Electricity Coordinating Council	
GO15	GO15 Reliable and Sustainable Power Grids	

Appendix 2. Interviews

I conduced 71 interviews with 81 participants, as some of the interviews included more than one person. The total is skewed due to the high number of interviews and participants in Mexico. But details are provided in Table A 2.

In the case of China, it was difficult to establish appropriate level of connections and I had envisioned to conduct more interviews with government official in a second round of interviews in 2020. Considering the health crisis, I decided to develop more interviews.

The original research schedule for Chile included on week before and one week during the UNFCCC Conference of the Parties scheduled in Santiago in 2019. However, due to social unrest the diplomatic conference was cancelled. I interview less representatives from the industry that I would have expected, due to their participation in ongoing negotiations to modify electricity service laws to reduce tariffs in response to social unrest. However, technical government officials were very responsive.

Finally, interviews in the UK were spaced in part due to the extraordinary elections called for the end of 2019. This meant that government officials, regulators and some public actors were legally limited to discuss policy, deferring interviews for after the general election of winter 2019.

A 2.1. Summary of interviews

Case study	Total interview	Total participants	Dates*	Format	Recorded	Women ratio
Chile	14	15	Nov-Dec/2019	In person and online	Mostly	20 %
UK	17	20	Oct/2019 Feb/2020	In person and online	Mostly	15 %

China	15	19	July/2019	In person	None	47 %
Mexico	25	33	May/2019	In person	Mostly	12 %
TOTAL	**71**	**87**				

* Very additional interviews were conducted outside these dates

Interviews in Chile

ID	Description of interviewee	Date of interview
4A01	Senior official at ministry	25-Nov-19
4A03	Former senior official at system operator	27-Nov-19
4A04	Senior official at regulatory agency	2-Dec-19
4A05	Senior official at system operator	2-Dec-19
4B01	Technical staff at international consultancy	26-Sep-19
4B02	Senior staff at trade association	27-Nov-19
4B03	Domestic engineering consultant	27-Nov-19
4B04	Legal staff at grid company	28-Nov-19
4C01	Former university staff and current policy expert	29-Sep-19
4C02	Senior university academic	26-Nov-19
4C03	Advocacy organisation staff	26-Nov-19
4C04	University academic	26-Nov-19
4C05	University academic	3-Dec-19
4C06	Staff at international cooperation agency	13-Jan-20

Interviews in the UK

ID	Type of interview	Date of interview
3A01	Official at regulator	07-Nov-19
3A02	Official at ministry	08-Nov-19
3B01	Head of trade association	27-Sep-19
3B02	Senior technical staff at code manager organisation	06-Nov-19
3B03	Senior expert with association to state owned company	14-Nov-19
3B04	Senior legal staff at code manager organisation	15-Nov-19
3B05	Former senior staff at grid company	16-Dec-19
3B06	Staff at trade association	16-Dec-19
3B08	Staff at system operators	22-Jan-20
3B09	Senior staff at grid company	22-Jan-20
3B10	Staff at grid company	17-Mar-20
3B07	Head of trade association	16-Jan-20
3C01	Senior staff at technical non-for-profit	09-Oct-19

3C02	Senior staff at technical non-for-profit	09-Oct-19
3C03	University academic	29-Oct-19
3C04	University academic	29-Oct-19
3C05	Technical staff at international consultancy	13-Oct-19

Interviews in China

ID	Type of interview	Date of interview
2A01	Junior research staff of state institute	15-Aug-19
2B01	Senior staff of industry trade association	18-Jul-19
2B02	Team of senior staff in industry research centre	22-Jul-19
2B03	Senior staff of industry trade association	7-Aug-19
2C01	Academic at local University	5-Jul-19
2C02	Junior staff at advocacy organisation	9-Jul-19
2C03	Senior staff at international organisation	10-Jul-19
2C04	Researcher at University-bases centre	17-Jul-19
2C05	Senior team at international organisation	16-Jul-19
2C06	Senior staff at international organisation	16-Jul-19
2C07	Senior staff at bilateral cooperation program	18-Jul-19
2C08	Academic at local University	19-Jul-19
2C09	Head of international organisation	16-Aug-19
2C10	Senior staff at bilateral cooperation program	19-Aug-19
2C11	Academic at foreign University	9-May-19

Interviews in Mexico

ID	Type of interview	Date of interview
1A01	Senior official at regulatory agency	6-May-19
1A02	Senior official at system operator	7-May-19
1A03	Senior official at ministry	15-May-19
1A04	Multiple staff at the system operator	15-May-19
1A05	Former commissioner at regulatory agency	9-May-19
1A06	Former commissioner	20-May-19
1A09	Full anonymity	24-May-19
1B02	Head of regulatory affairs for a private company	9-May-19
1B03	Head of regulatory affairs for a private company	9-May-19
1B04	CEO of private company	14-May-19
1B05	CEO of private company	14-May-19

1B06	Senior staff of industry trade association	16-May-19
1B07	Head of regulatory affairs for a private company	20-May-19
1B08	CEO of private company	20-May-19
1B09	CEO of private company	22-May-19
1B10	Senior staff of state-owned company	22-May-19
1C01	Head of international cooperation program	1-May-19
1C02	Senior team of international cooperation program	6-May-19
1C03	Senior staff in international cooperation	7-May-19
1C04	Senior staff at advocacy organisation	7-May-19
1C06	Technical advisor to local advocacy organisation	7-May-19
1C07	Academic	13-May-19
1C08	Head of international cooperation program	14-May-19
1C09	Team of academic	21-May-19
1C10	Head of academic department	21-May-19

Appendix 3. Case selection

I consider the four cases, Chile, China, Mexico and the UK to be relevant on their own right because of their historical and regional significance to a wide audience. But the case selection was based on theoretical and practical research conditions.

I selected four cases that fitted to key criteria regarding the comparability based on liberalisation level and the position of the system operator. The electricity sector in these jurisdictions also share other relevant characteristics. These cases had more than 1 per cent of solar and wind energy by 2015. Forecasts showed positive growth rates and the 5 per cent threshold had already been crossed or was going to be crossed during the period of research. It was important to work with cases that were experiencing important growth rates. A case like Spain had a large share of wind and solar energy, but a stalled growth rate.

Another relevant criterion is the dominance of fossil fuel thermal power generation in the generation mix. Cases with high share of hydropower energy can manage wind and solar variability through minor changes to operation schedules, due to the hydropower turbines capability of raping in short time. For example, Brazil is a large electricity market with liberalised market and growing share of wind and solar energy, but their most abundant energy source for electricity generation is hydropower. Hence, Brazil is not expected to experience significant problems of curtailment. That particular jurisdiction will have different operation and planning challenges compared to those of energy systems that rely on fossil fuel thermal power generation.

Finally, it is important to clarify that apart from liberalised and partially liberalised regimes, there are jurisdictions with very little features of liberalisation. Currently South Africa and Saudi Arabia

are examples of non-liberalised markets. Before 2013, Mexico would be categorised in this group. However, this group of jurisdictions was dismissed from case selection to maintain the research project at an appropriate scale. As far as I am aware, non-liberalised regimes have not deployed independent system operators.

The following table shows a selected number of cases of large economies, with growing share of wind and solar, still dependent on fossil fuel thermal power generation, that could have been used as cases for research.

Table A 3.1. Sample of potential cases for research

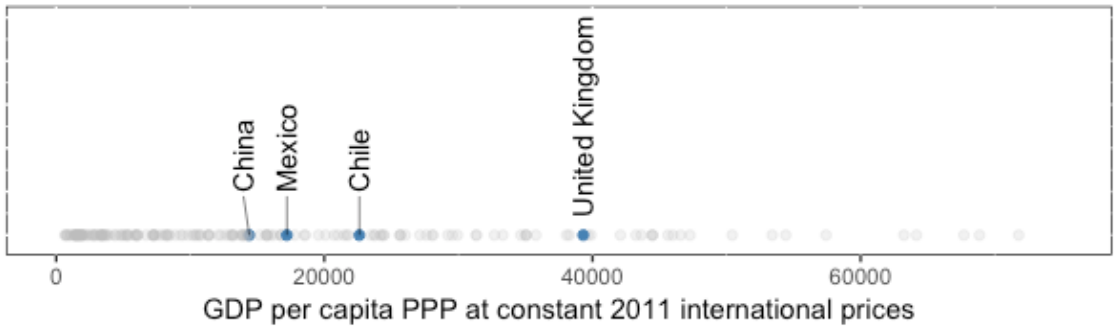
	Liberalised market	Partially liberalised market	Non-liberalised market
Independent System Operator	**Chile**, Australia, US California, US Texas	**Mexico**	–
No Independent System Operator	**UK**, Denmark, Germany, Japan, Spain	**China**, India, Vietnam	South Africa, Saudi Arabia

In light of existing comparative literature on energy policy that divides developed and developing countries for case comparison, the case selection as a reasonable choice on the basis of the institutional context of the countries. Figure 2 depicts a wide gap in GDP per capita between the UK on the one hand, and China, Mexico and Chile on the other. However, average income level is relevant to explain the past trends in the uptake of renewable energy through the use of economic incentives, but as renewable energy costs diminish, the economic burden of deployment diminishes.

It is more appropriate to account for measurements of government capacity and regulatory quality at a national level. The Worldwide Governance Index 2017 (Kaufmann and Kraay 2018) reports

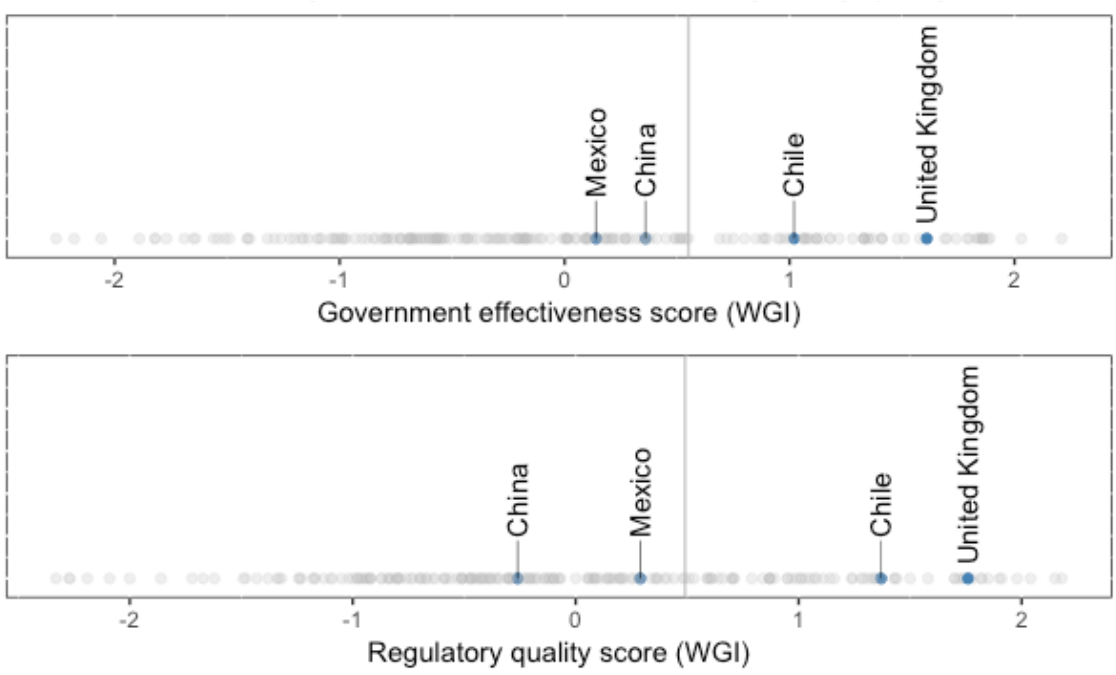
scores on government effectiveness and regulatory quality, which are presented in Figure 11. A dividing line has been drawn according to Andrews, Pritchett, and Woolcock's (2017) criteria to distinguish of the high government effectiveness group (at the score value of Uruguay). Chile and the UK are significantly closer to the upper boundary of the score, while China and Mexico are in the middle of the range, confirming the suitability of this case comparison.

Figure A 3.1. GDP per capita PPP (2016)



Source: Author based on data from World Bank (2017).

Figure 11. Scores on government effectiveness and regulatory quality



Source: Author based on Worldwide Governance Index 2017.

Appendix 4. Node-network description

The empirical research relied on network elicitation as a tool for structuring qualitative analysis of the regulatory ecosystem. The relations data gathered to develop the networks graphs can also be used to conduct a quantitative characterisation of the network structure and relations attributes of each specific node.

The main difference to the most common quantitative network analysis is the fact that the networks in this research are not the entire population of the electricity sector field in any of the cases, nor are they a sample of the population of actors. Furthermore, for the largest public organisations, the elicitation exercise is fettered by the limited awareness of each specific individual about interactions. I attempted to interview more than one individual in some of the largest organisations, however this was not always possible, nor does it guarantee a much better depiction of all the relations available to the actor. There are also the limitations to recollection during the interview.

However, the quantitative characterisation of the network does provide some additional avenues to corroborate that the qualitative description is accurate. Network analysis and characterisation is based on the use of algorithms to describe the entire network or specific nodes based on their position within the network.

This appendix includes the results for a number of descriptive statistics calculated form the network database for each country with a discussion on its significance to the analysis and the expectations of this research. I focus on three specific types of indicators:

1) Degree

2) Partition or modularity class

3) Authority-hubs (HITS algorithm)

The measure of *Degree* refers to the total number of linkages or edges between the node of interest and the rest of the nodes. Further information can be gathered if we know the direction of the relation; in this research it means the source and destination of the specialised knowledge. Based on the direction it is possible to differentiate between *In-degree* and *Out-degree* depending on whether the node of interest is the destination or the source, respectively. The measure of degree-centrality, the absolute counts of degree, in-degree or out-degree, can be theoretically significant, for example if we establish that the most important the regulatory authority, the most actors will attempt to establish a relation to them. Similarly, authority we would expect the delegated authority would have a highest degree centrality.

The analysis of partition or modularity is used to characterised groups that are more connected between each other than to the rest of the networks. A cluster, for example, refers to a group of nodes that are tightly connected. This analysis is useful because, as shown in the classical works from Padgett & Ansell (1993) on the Renaissance Medici family and on Burt (1997) on social capital, benefits accrue to those that can close the holes between groups of clusters of actors. Theoretically, highly clustered groups result in less opportunities for the exchange of knowledge but raise the potential importance of the few actors able to bridge between groups. This is particularly important if there are bridges other than the authority. However, due to the characteristics of the network clustering statistics in all of the cases were not meaningful, which the structural analysis did not clearly showed well defined structures. This result is related to the type of network elicitation. First, the lack of entire population reduced the chances of clusters to appear in the data. And secondly, the lack of a hard limit on how interviewees reported linkages means that they were able to be expansive.

Finally, one particular approach to provide a synthesis of these types of phenomena is rating through weighting each edge based on the relative interconnectedness of the nodes it is connected recursively. The Hyperlink-Induces Topic Search or HITS was developed to rate web pages and differentiate between a value for *authority* and a value for *hub*. A high authority value refers to holding high in-degree from relatively well-connected nodes (the sum of the scaled hub values that point to the node). And a high hub value refers to the holding a high out-degree towards high authority nodes. Other calculation of this type includes those of search engines or journals impacts factor. Theoretically, these computations resemble the language of regulatory authority and key knowledge providers, where the most rich or active knowledge holders would hold the highest hub values, while the authorities would be well interconnected to this knowledge hubs. This measurement takes the most advantage of direction in the relations of knowledge exchange, and therefore report the results that best match the theoretical proposition.

This analysis was conducted using the software Gephi which included built-in option to perform the calculations, including that of the HITS algorithm.

Node statistics for Chile

Multiple variable order by modularity class

Acronym	Country	Modularity class	Hub	Authority	In-degree	Out-degree	Degree
ACERA AG	Chile	0	0.09	0.08	1	1	2
Ministry of Energy	Chile	0	0.10	0.56	16	2	18
CAF	Chile	0	0.09	0.00	0	1	1
DoE	USA	0	0.09	0.00	0	1	1
IADB	Intl	0	0.09	0.08	1	1	2
Ministry of Finance	Chile	0	0.09	0.00	0	1	1
Panel	Chile	0	0.09	0.00	0	1	1
CCME	Chile	1	0.09	0.13	2	1	3
CIFF	UK	1	0.03	0.00	0	1	1
UC	Chile	1	0.47	0.16	7	12	19
Corfo	Chile	1	0.00	0.14	2	0	2
SwitzerlandGov	Switzerland	1	0.03	0.00	0	1	1

Avina	Chile	1	0.00	0.08	1	0	1
UC Denver	USA	1	0.10	0.00	0	2	2
Chile Sustentable	Chile	2	0.29	0.19	5	5	10
Congress	Chile	2	0.00	0.05	1	0	1
FIMA (NGO)	Chile	2	0.03	0.00	0	1	1
Grenpeace	Intl	2	0.03	0.00	0	1	1
Generadoras AG	Chile	3	0.00	0.22	4	0	4
GiZ	Germany	3	0.38	0.20	4	9	13
50HRZ	UK	3	0.00	0.06	1	0	1
Ministry of Environment	Chile	3	0.09	0.06	1	1	2
UT FSM	Chile	3	0.11	0.00	0	2	2
CNE	Chile	4	0.07	0.45	10	1	11
Coordinador	Chile	4	0.26	0.43	13	4	17
Local consultants	Chile	4	0.33	0.00	0	6	6
CIGRE	UK	4	0.07	0.00	0	1	1
E.E. AG	Chile	4	0.29	0.20	4	5	9
SEC	Chile	4	0.05	0.16	3	2	5
Transelec	Chile	4	0.24	0.11	3	3	6
Minisry of Transportation	Chile	4	0.07	0.00	0	1	1
Private companies	Chile	4	0.14	0.05	1	3	4
PUC	Chile	4	0.30	0.00	0	7	7

Node statistics for the UK

Multiple variable order by modularity class

Acronym	Country	Modularity class	Hub	Authority	In-degree	Out-degree	Degree
ENA	UK	0	0.22	0.65	17	5	22
Cambridge	UK	0	0.19	0	0	2	2
Devolved Gov	UK	0	0.12	0.06	1	1	2
Durham	UK	0	0.12	0	0	1	1
Euroelectric	Int	0	0.12	0	0	1	1
Eurogas	Int	0	0.12	0	0	1	1
IEA	Intl	0	0.12	0	0	1	1
JRC	UK	0	0.12	0	0	1	1
New Castle	UK	0	0.12	0	0	1	1
Oxford	UK	1	0.17	0	0	5	5
Scottish Power	UK	1	0.13	0	1	4	5
Greenpeace	Int	1	0.02	0	0	2	2
DNOs	UK	1	0	0.18	3	0	3

Local governments	UK	1	0	0.1	3	0	3
EDF	France	1	0	0.03	1	0	1
MAA/CAA	UK	1	0	0.02	1	0	1
ES Catapult	UK	2	0.49	0.21	8	11	19
Private Consultancies	UK	2	0.29	0	0	4	4
Imperial	UK	2	0.24	0	0	4	4
Strathclyde	UK	2	0.16	0	0	2	2
Carbon Trust	UK	2	0.13	0.06	2	3	5
CCC	UK	2	0.11	0.09	1	2	3
Manchester	UK	2	0.08	0	0	2	2
BNEF	UK	2	0.07	0	0	1	1
National Grid	UK	2	0.05	0.35	9	4	13
Arup	UK	2	0.04	0	0	1	1
Birmingham	UK	2	0.04	0	0	1	1
Ricardo Energy	UK	2	0.04	0	0	1	1
Innovate UK	UK	2	0	0.16	3	0	3
Entrepreneur	UK	2	0	0.09	1	0	1
Infraestructure Commission	UK	2	0	0.01	1	0	1
NG USA	UK	2	0	0.01	1	0	1
Renewables UK	UK	3	0.33	0.1	4	7	11
BEIS	UK	3	0.13	0.22	7	2	9
E3G	UK	3	0.04	0	0	1	1
Crown Estates	UK	3	0.02	0	0	1	1
ORE Catapult	UK	3	0.02	0	0	1	1
CREA	China	3	0	0.06	1	0	1
DEFRA	UK	3	0	0.06	1	0	1
LCCC	UK	3	0	0.02	1	0	1
Elexon	UK	4	0.29	0.13	2	5	7
Citizens Advise	UK	4	0.22	0	0	3	3
Ofgem	UK	4	0.19	0.31	7	2	9
Energy UK	UK	4	0.06	0.15	2	1	3
ETC	UK	4	0.06	0.01	1	1	2
HVDC Centre	UK	4	0.06	0	0	1	1
Smith Institute	UK	4	0.06	0	0	1	1
NG ESO	UK	4	0.06	0.34	9	2	11
RTE	France	4	0	0.01	1	0	1

Node statistics for China

Multiple variable order by modularity class

Acronym	Country	Modularity class	Hub	Authority	In-degree	Out-degree	Degree
Climate Group	UK	0	0.05	0.00	0	1	1
CREEI	China	0	0.11	0.21	4	2	6
CREIA	China	0	0.26	0.24	7	4	11
CREIC	China	0	0.04	0.00	0	1	1
Greenpeace	USA	0	0.05	0.08	1	1	2
RMI	USA	0	0.05	0.08	1	1	2
WRI	USA	0	0.05	0.00	0	1	1
C40	USA	1	0.00	0.08	1	0	1
CIFF	UK	1	0.00	0.17	3	0	3
CMRI	China	1	0.00	0.07	1	0	1
CNREC	China	1	0.34	0.40	6	8	14
DEA (Dk)	Denmark	1	0.40	0.17	2	12	14
GiZ (De)	Denmark	1	0.02	0.33	4	1	5
IEA	Intl	1	0.02	0.00	0	1	1
Local NEA	China	1	0.00	0.08	1	0	1
NAMA Facility	Germany	1	0.00	0.08	1	0	1
NREL	USA	1	0.02	0.14	2	1	3
SGERI	China	1	0.22	0.12	4	5	9
CEC	China	2	0.20	0.20	12	4	16
CEPRI	China	2	0.05	0.00	0	2	2
Energienet	Denmark	2	0.01	0.00	0	1	1
NRDC (NGO)	USA	2	0.04	0.15	2	1	3
State Grid	China	2	0.04	0.06	4	1	5
EU-China Platform	Intl	2	0.00	0.04	1	0	1
Huaneng	China	2	0.04	0.00	0	1	1
Datang	China	2	0.04	0.00	0	1	1
Huadian	China	2	0.04	0.00	0	1	1
Guodian	China	2	0.04	0.00	0	1	1
InvestCorpo	China	2	0.04	0.00	0	1	1
CREMC	China	3	0.04	0.00	0	1	1
DRC	China	3	0.00	0.00	0	1	1
EPPEI	China	3	0.11	0.19	4	2	6

NEA	China	3	0.00	0.38	7	1	8
State Council	China	3	0.00	0.00	2	0	2
EF	USA	4	0.05	0.26	4	1	5
RAP	USA	4	0.55	0.08	1	12	13
Southern China Grid	China	4	0.04	0.00	1	1	2
BJ Power Exchange	China	4	0.01	0.11	1	1	2
GD Power Exchange	China	4	0.00	0.11	1	1	2
ERI	China	5	0.03	0.34	5	1	6
MEE-CC	China	5	0.00	0.03	1	0	1
NCEPU	China	5	0.44	0.00	0	10	10
NDRC	China	5	0.00	0.17	3	0	3
Tsinghua U	China	5	0.00	0.08	1	0	1
ICCSD - TU	China	5	0.16	0.00	0	5	5
EDF (NGO)	USA	5	0.00	0.03	1	0	1
CAS	China	5	0.00	0.08	1	0	1

Node statistics for Mexico

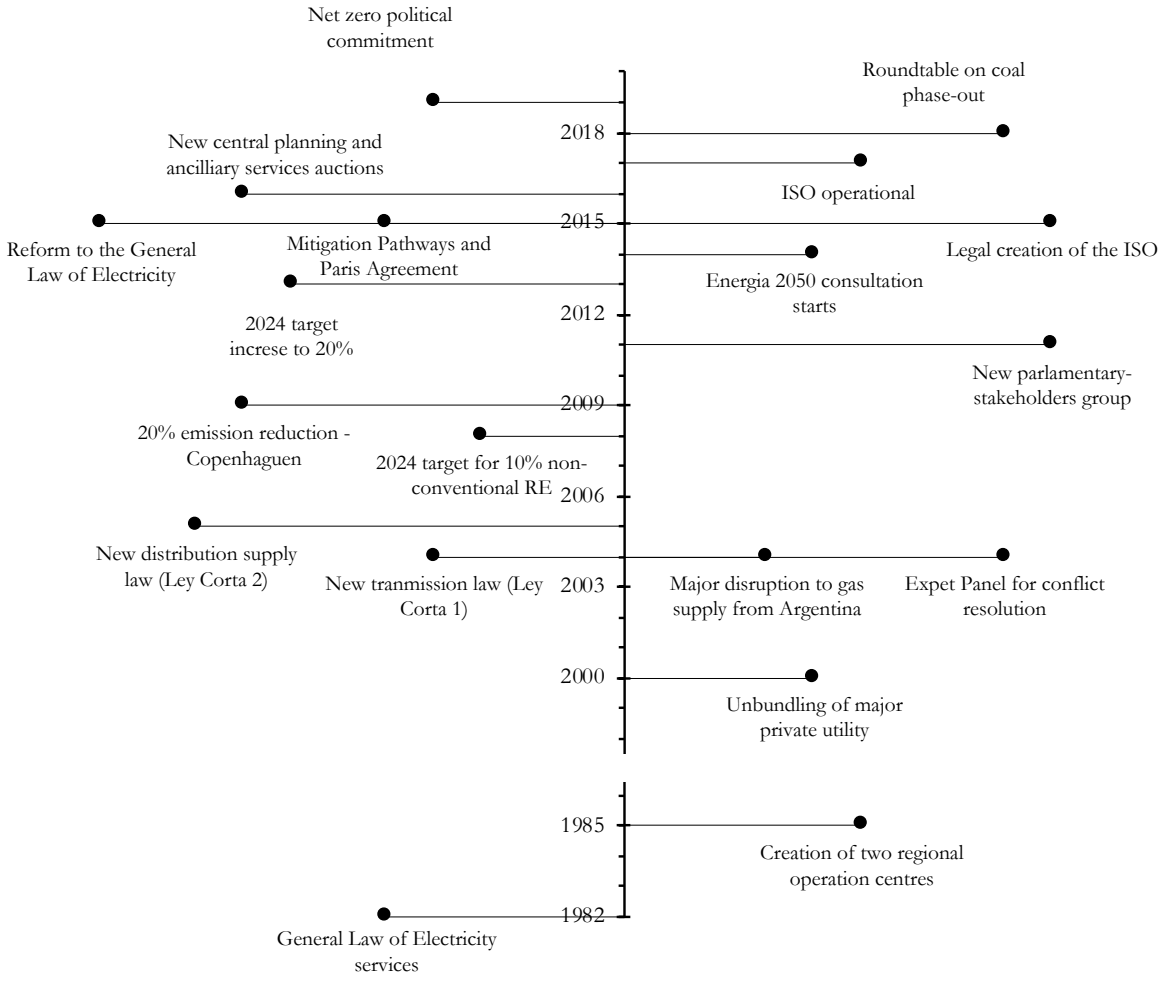
Multiple variable order by modularity class

Acronym	Country	Modularity class	Hub	Authority	In-degree	Out-degree	Degree
CENACE	Mexico	0	0.17	0.45	15	2	17
G015	France	0	0.08	0.00	0	1	1
IFC	USA	0	0.08	0.00	0	1	1
Ombudsman	Mexico	0	0.08	0.00	0	1	1
SMN	Mexico	0	0.08	0.00	0	1	1
UMSNH	Mexico	0	0.08	0.00	0	1	1
Utility Est	Chile	0	0.08	0.00	0	1	1
ICM	Mexico	1	0.20	0.22	7	7	14
ASOLMEX	Mexico	1	0.25	0.08	3	3	6
ANES	Mexico	1	0.10	0.03	1	1	2
Agora (DE)	Germany	1	0.04	0.00	0	1	1
PwC	Spain	1	0.04	0.00	0	1	1
USAID	USA	1	0.04	0.00	0	1	1
Private_Gen	Mexico	1	0.01	0.00	0	1	1
CESPEDES	Mexico	1	0.00	0.03	1	0	1
SHCP	Mexico	1	0.00	0.03	1	0	1
INEEL	Mexico	2	0.41	0.06	1	9	10
DEA (Dk)	Denmark	2	0.37	0.01	2	9	11

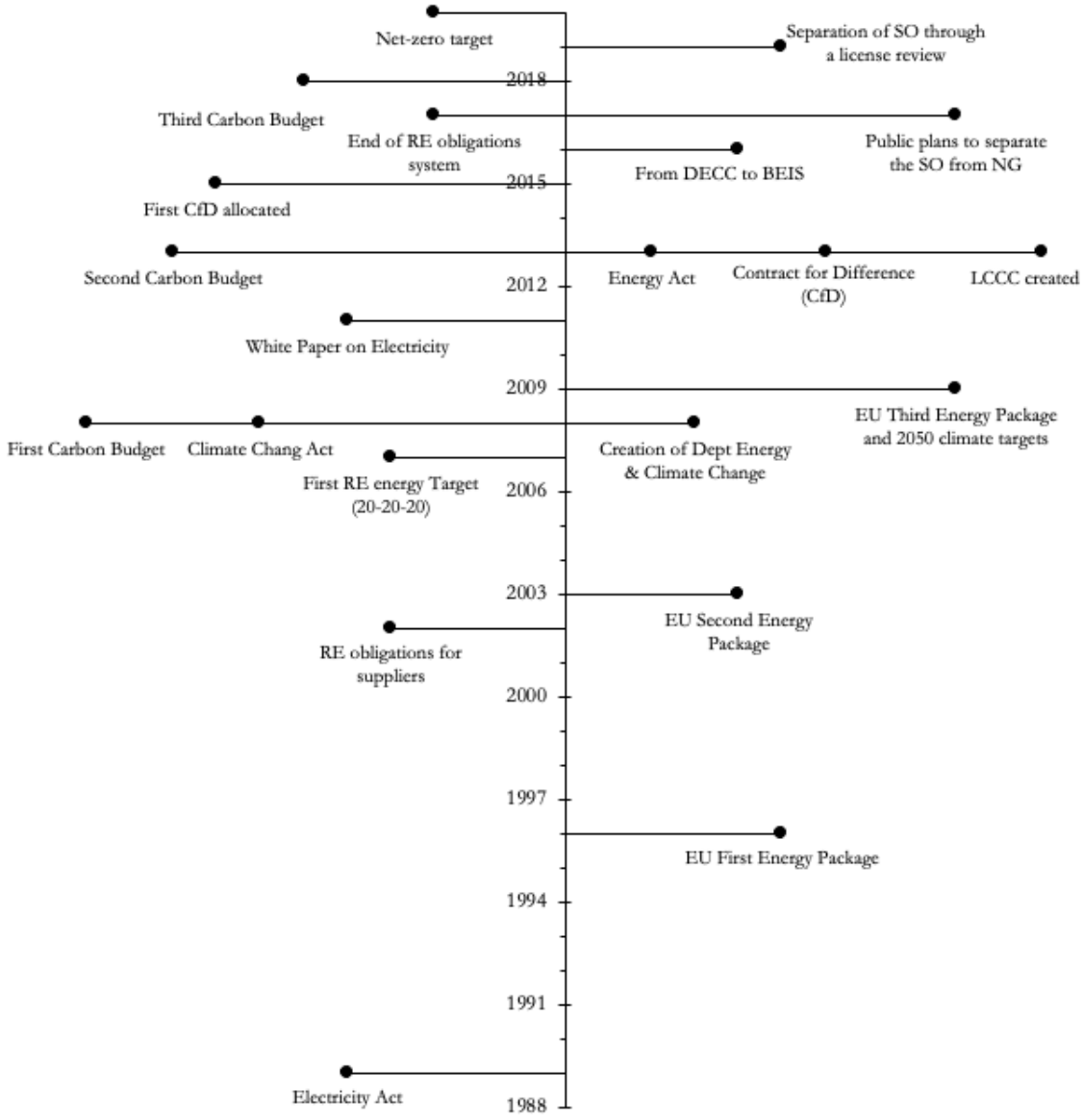
UNAM	Mexico	2	0.18	0.06	1	3	4
CFE_Trans	Mexico	2	0.14	0.07	1	2	3
Energinet	Denmark	2	0.08	0.00	0	2	2
CFE Corp	Mexico	2	0.08	0.35	10	1	11
CFE_Gen	Mexico	2	0.06	0.07	1	1	2
DTU (DK)	Denmark	2	0.00	0.00	0	1	1
Protec	Mexico	2	0.00	0.07	1	0	1
Large consumers	Mexico	2	0.00	0.06	1	0	1
AMDEE	Mexico	3	0.17	0.08	2	2	4
NERC	USA	3	0.15	0.00	0	2	2
CFE_Dist	Mexico	3	0.14	0.00	0	2	2
ESTA	USA	3	0.08	0.00	0	2	2
CRE	Mexico	3	0.10	0.46	16	1	17
MIM	Mexico	3	0.08	0.01	1	1	2
CANAME	Mexico	3	0.08	0.00	0	1	1
CENAM	Mexico	3	0.08	0.00	0	1	1
NARUC	USA	3	0.08	0.00	0	1	1
WECC	USA	3	0.08	0.00	0	1	1
NREL	USA	4	0.26	0.17	6	7	13
IPN	Mexico	4	0.16	0.00	0	3	3
IER-UNAM	Mexico	4	0.16	0.00	0	3	3
CFE_Geo	Mexico	4	0.06	0.04	1	1	2
CIDE	Mexico	4	0.03	0.00	0	1	1
WRI	USA	4	0.03	0.00	0	1	1
SEMARNAT	Mexico	4	0.00	0.11	2	0	2
GiZ (DE)	Germany	5	0.35	0.06	1	5	6
CENAGAS	Mexico	5	0.17	0.00	0	2	2
IADB	USA	5	0.10	0.00	0	1	1
Iberdrola	Spain	5	0.10	0.00	0	1	1
IMCO	Mexico	5	0.10	0.00	0	1	1
Vestas	Denmark	5	0.10	0.00	0	1	1
WWF	USA	5	0.10	0.00	0	1	1
SENER	Mexico	5	0.00	0.57	18	0	18

Appendix 5. Historical timeline of cases

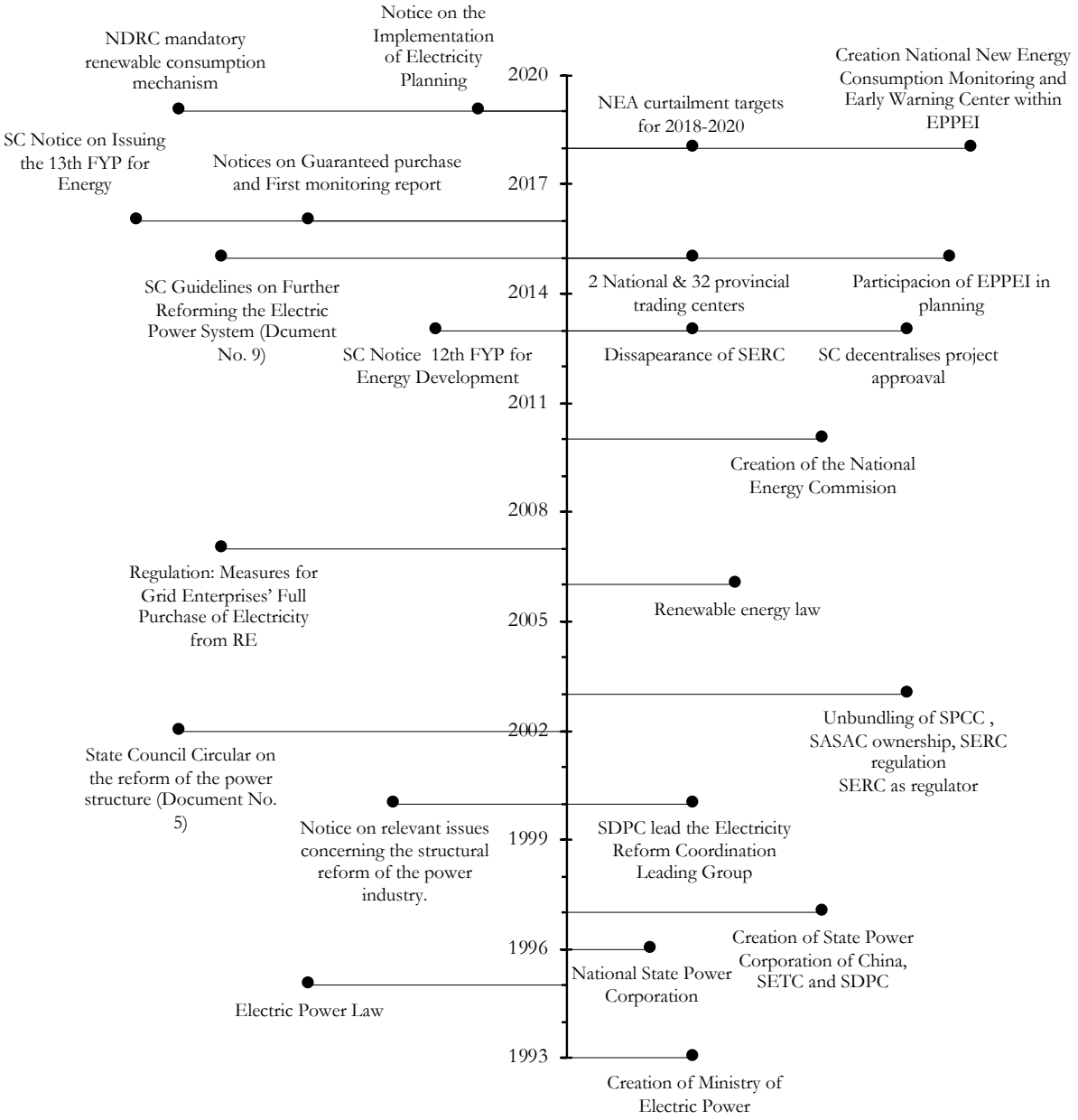
Timeline of electric power system governance in Chile



Timeline of electric power system governance in the UK

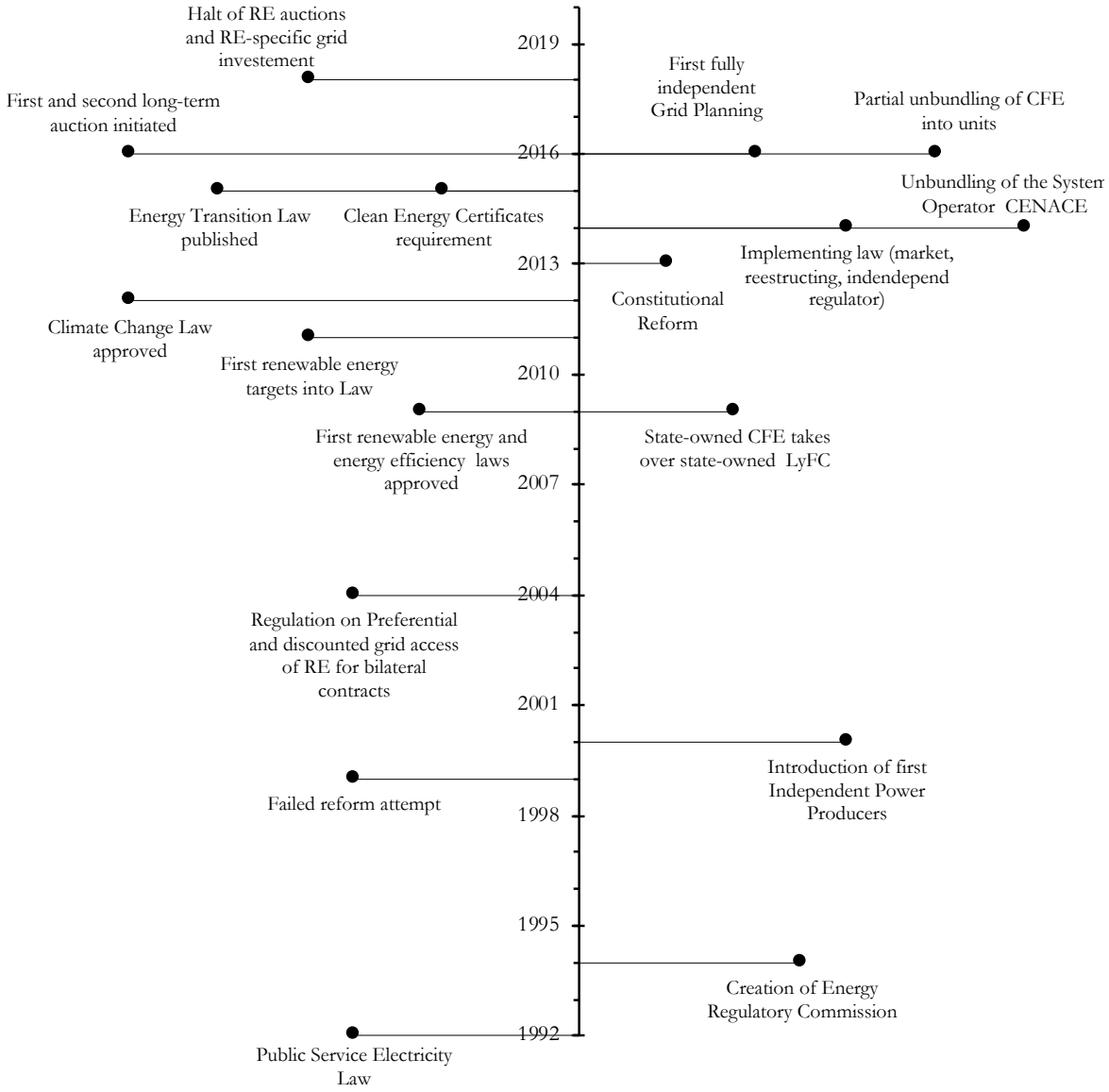


Timeline of electric power system governance in China



Source: Author.

Timeline of electric power system governance evolution in Mexico



Source: Author.