Electricity market re-design in Great Britain: A proposed new design and lessons on implementation

Submitted by Thomas Pownall to the University of Exeter

as a thesis for the degree of

Doctor of Philosophy in Geography

February 2022

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Pownall

“I always get to where I’m going by
walking away from where I have been”

Winnie the Pooh – A. A. Milne

Abstract

Implementing electricity market re-design within Great Britain is required to facilitate the goal of a net zero electricity system. The electricity market design as an institution determines the services which can access value and therefore the rules embedded within the design are an important influence on future investment decisions as well as current energy economics. A continuation of the current rules which reflect an outdated paradigm based upon large-scale, centralised, and predominantly fossil fuel thermal generating units hinders the UK's policy objective of a net zero power sector by 2035. Therefore, electricity market re-design is essential to bring forward investment into the technologies, new modes of operation and user practices which are aligned with net zero ambitions.

Whilst multiple proposals for changes to the existing design exist, these focus on addressing particular aspects of the electricity market design and do not provide the holistic blueprint required by policymakers, nor do these offer guidance on the process of implementation.

To address this gap, the technique of modularisation was employed to identify where alterations to Great Britain's electricity market design were required. Where issues had been identified, alternative arrangements were sourced from an extensive literature review of 49 papers with proposals for electricity market reform. This led to the creation of a strawperson proposal which was appraised and validated through 41 expert semi-structured interviews, presented at national and international conferences and through the process of academic peer-review. The proposed design provides a blueprint for policymakers which is an augmentation of the current design, aligned to net zero and addresses the issues identified with the current institutional setup.

Lessons on implementation were gathered from an additional literature review and insights from the same semi-structured interviews. This led to several key findings. First, there is widespread support for electricity market re-design across the majority of interviewees and within the literature. Second, divergences emerged in how electricity market re-design should proceed; via small-scale incremental changes or a largescale implementation akin to the New Electricity Trading Arrangements. This thesis argues for the latter. Compounding these debates on implementation is the increased diversity of market participants who offer innovations in how the institution operates, but only if

their ideas are listened to, which under current framings will be difficult due to the scale of regime resistance.

The implications of this research provides policymakers, regulators and fellow actors involved within the field of electricity market design with a case for change and an appraised, holistic blueprint design and lessons on implementation.

Acknowledgements

Speaking to fellow academics, supervisors and dishevelled fourth year PhD candidates, it was clear that writing a thesis would be tough. However, it has been a pleasure to reflect upon the happy memories borne throughout this process.

Whilst my name is on the front cover, this thesis would not have been possible without the guidance provided by the incredible people I have had the pleasure of meeting along the way. To those who have helped me, even without realising it, this acknowledgement is for you.

First and foremost, to my supervisors Prof Catherine Mitchell and Dr Iain Soutar. I am extremely grateful for all of your guidance, time, and expertise throughout this PhD. You have pushed my horizons, made me challenge my assumptions and shaped the researcher that I am today. Put simply, I could not have asked for better supervisors, and I will be forever thankful for your support. I hope that you take ownership of this thesis, as without you both it would not have been possible.

To the Energy Policy Group, it has been a true pleasure to have been welcomed into a group of such talented academics and just incredible people all round. With the complex issues that we are facing in society, I am comforted in knowing that you are working on the solutions. Though this stint with the EPG has concluded, one does not simply leave the EPG.

To those who kindly offered their hard-earned time to help me with this research, thank you. You provided me with the basis for this thesis, and importantly were someone to get excited about electricity market design with. I will forever be thankful for this. I would also like to thank the University of Exeter and the EPSRC for supporting my research.

To the incredible friends I have been lucky enough to know, including the GBB, the aptly named Colouring Crew and those in Cornwall too many to name, I cannot thank you enough for the laughs over the years. You don't know how much those meant to me.

To my wonderful family, your support throughout this PhD has been immeasurable, and I wouldn't be sat here if it wasn't for you. Thank you one and all. I promise that I will get a job in the near future.

Finally, Lizzie. I’m not sure where to begin. The support you have given me over the years has been nothing less than exceptional. Without you I can say with certainty that I would not be where I am today. Though the PhD has had its fair share of tough moments, when I think back on this period of my life a smile is brought to my face and that is ultimately thanks to you. Thank you for being you.

Declaration of published work

- WILLIS, Rebecca et al. 2019. Getting Energy Governance Right: Lessons from IGov. Available at: http://projects.exeter.ac.uk/igov/wp-content/uploads/2019/08/IGov-Getting-energy-governance-right-Sept2019.pdf
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- SANDYS, Laura and Thomas POWNALL. 2020. 'ReCosting Energy: Powering for the Future' [online]. Available at: http://www.challenging-ideas.com/wp-content/uploads/2021/02/FINAL-DOC-HR-1.pdf.
- POWNALL, Thomas, Iain SOUTAR and Catherine MITCHELL. 2021. 'Re-Designing GB's Electricity Market Design: Recognising the Value of Distributed Energy Resources'. Energies 14(1124), [online]. Available at: https://www.mdpi.com/1996-1073/14/4/1124. This publication provides an option that BEIS is considering within their Review of Electricity Market Arrangements.

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Abbreviations

ACER	Agency for The Cooperation of Energy Regulators
AR	Allocation Round
BEIS	Department of Business, Energy and Industrial Strategy
BETTA	British Electricity Trading and Transmission Arrangements
BMU	Balancing Mechanism Unit
BSC	Balancing and Settlement Code
BSP	Bulk Supply Point
BSUoS	Balancing Services Use of System
BT	British Telecom
BTM	Behind the Meter
CCC	Committee on Climate Change
CCGT	Combined Cycle Gas Turbines
CEGB	Central Electricity Generating Board
CEP	Clean Energy Package
CfD	Contracts for Difference
CMA	Competition and Markets Authority
CRM	Capacity Remuneration Mechanism
CVA	Central Volume Allocation
DAH	Day Ahead
DC	Dynamic Containment
DECC	Department of Energy and Climate Change
DER	Distributed Energy Resources
DI	Discursive Institutionalism
DLMP	Distribution Locational Marginal Pricing
DNO	Distribution Network Operator
DRO	Decentralised Reliability Option
DSO	Distribution Systems Operator
DSP	Distributed Service Provider
DSR	Demand Side Response
DTI	Department for Trade and Industry
DUoS	Distribution Use of Service
EBGL	Guidelines on Electricity Balancing
ECVNA	Energy Contract Volume Notification Agent
EDR	Electricity Demand Reduction
EEX	European Energy Exchange
EFAs	Exchange-Traded Forward Agreements
EFPM	Energy Floor Price Model
EMR	Electricity Market Reform
ERCOT	Electric Reliability Council of Texas
ESO	Electricity System Operator
EV	Electric Vehicles
FERM	Firm Energy Revenue Model
FES	Future Energy Scenarios
FiT	Feed-In Tariffs
FPN	Final Physical Notifications
FTR	Financial Transmission Rights
GB	Great Britain
GHG	Greenhouse Gasses

GSP	Grid Supply Point
GW	Gigawatt
GWh	Gigawatt-Hours
HI	Historical Institutionalism
HVDC	High Voltage Direct Current
ICE	Intercontinental Exchange
ID	Intraday
IEA	International Energy Agency
IISO	Independent Integrated System Operator
IMRP	Intermittent Market Reference Price
IoT	Internet of Things
IPCC	Intergovernmental Panel on Climate Change
ISO	Independent System Operator
LCCC	Low Carbon Contracts Company
LCOE	Levelised Cost of Electricity
LEM	Local Energy Market
LMP	Locational Marginal Pricing
MBSS	Monthly Balancing Services Summary
MDCSM	Market Driven Cost of Service Model
MLP	Multi-Level Perspective
MW	Megawatt
MWh	Megawatt-Hours
NEMO	Nominated Electricity Market Operators
NETA	New Electricity Trading Arrangements
NFFO	Non-Fossil Fuel Obligation
NGET	National Grid Electricity Transmission
NGGT	National Grid Gas Transmission
OCGT	Open Cycle Gas Turbine
ODFM	Operation Downward Frequency Management
OPEX	Operational Expenditure
OTC	Over the Counter
PPA	Power Purchase Agreement
PV	Photovoltaics
RAB	Regulated Asset Base
RECs	Regional Electricity Companies
REMIT	Regulation on Wholesale Energy Market Integrity and Transparency
RI	Rational Choice Institutionalism
ROCs	Renewable Obligation Certificates
RoI	Return on Investment
SCR	Significant Code Review
SES	Smart Energy System
SI	Sociological Organisational Institutionalism
SNAPS	System Needs and Product Strategy
SO	System Operator
SPEN	Scottish Power Energy Networks
SR	Strategic Reserve
SRMC	Short-Run Marginal Cost
STOR	Short Term Operating Reserve
STS	Science, Technology and Society

STT	Socio-Technical Transitions
SVA	Supplier Volume Allocation
TA	Transitional Arrangement
TEC	Transmission Entry Capacity
TM	Transition Management
TNUoS	Transmission Network Use of System Charges
TSO	Transmission System Operator
UKPN	UK Power Networks
VFA	Volume Firming Agreements
VI	Vertical Integration
VLP	Virtual Lead Parties
VRE	Variable Renewable Energies
WPD	Western Power Distribution

1.0 Introduction

In August 2021 the Intergovernmental Panel on Climate Change (IPCC) Working Group I released their summary for policymakers, which laid out a stark warning on the impact of anthropogenic climatic change (IPCC 2021). The report stated that "human-induced climate change is already affecting many weather and climate extremes in every region across the globe", suggesting that global heating above pre-industrial temperatures will exceed the 1.5°C and 2°C thresholds during this century unless deep greenhouse gases (GHG) reductions are made in the coming decades" (IPCC 2021: 10). The need to act fast to limit climate change is widely recognised and has been expressed by a variety of organisations such as the International Energy Agency World Energy Outlook (2019), HM Government's Energy White Paper (2020a) and the Committee on Climate Change's (CCC) net zero report (2019) and their report to Parliament on emission reductions (2021). The UK has legislated a legally binding target for the UK to achieve net zero by 2050, with the power sector itself being decarbonised by 2035, and signed up to international agreements, such as the Paris Accord (BEIS 2016a, 2019a, 2021a; UNFCCC 2016).

The UK energy sector, through emissions from transport, heat, and the generation of electricity, is the largest emitter of GHG, the main anthropogenic contributor to climate change (BEIS 2018a). Therefore, while it is important to tackle the emissions from all sectors, as the largest emitter of GHG this necessitates research into reducing the energy sectors' contribution.

Reductions in emissions within the UK over the last decade have largely resulted from changes in the fuel sources used to produce electricity, in particular transitioning away from coal, towards gas and variable renewable energy (VRE) resources, such as onshore and offshore wind alongside the increased deployment of energy efficiency measures (Ofgem 2020a; BEIS 2021b). The CCC (2019, 2021) has stated that for the UK to meet the net zero target, the contribution of renewable and low-carbon forms of generation must increase from the current ~50% share to 95% by 2050, whilst fossil fuel use is required to decrease by 95%. Although the primary focus of this thesis is renewable energy, it should be emphasised that any increase in renewable energy deployment should happen in a system that uses energy efficiently.

Policy to reduce GHG emissions has both increased deployment and reduced the costs of renewable energy generation (BEIS 2018a; IEA 2018). However, some argue that the governance of the electricity system, the policies, institutions, regulations, market rules, incentives including the market design continue to stifle the transition to a cost effective and high renewable future energy system (Mitchell 2017a; Energy Systems Catapult 2021).

The focus of this thesis is Great Britain's (GB) electricity market design. This introductory chapter will explore what is meant by 'electricity market design', highlight how the requirements of this institution have changed in the context of an evolving GB[1] energy system and outline the scope and structure of this thesis.

1.1 The electricity market design and its importance in the facilitation of net zero

Central to the economics of the electricity sector within liberalised electricity systems is the electricity market design. This institution is defined by the European Commission as:

> "[The electricity] market design is the 'rulebook' for energy market players. The ***rules*** establish the general principles and technical details on energy market participation, as well as specify ***rights*** and ***responsibilities*** among market participants. 'Market design' is the 'software' on which our energy markets run, while the energy infrastructure is the 'hardware'" [emphasis added] (European Commission 2016: 1).

An electricity market design can therefore be viewed as the 'rules' which underpin and determine how electricity markets functions. These rules are legal texts known as 'codes' which market participants must adhere to in order to access the electricity market. The general principles and technical details laid out in these rules will determine the preferred forms of technologies which can access into a market, and therefore compete to secure revenue streams. The rights and responsibilities of

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[1] Energy policy (except matters regarding nuclear generation) was devolved to Northern Ireland in 1998, and therefore they have developed their own electricity market design. See EIRGRID (2019) for more details.

participants are also stated within these codes. For example, in adhering to the balancing and settlement code (BSC), a market participant has the right to raise a change of these rules and has the responsibility to ensure that sufficient credit cover has been lodged. There is some consensus that the rules which govern participation within electricity markets are important as they determine the winners and losers by defining which services can access revenue flows (e.g. power and flexibility) and the technical characteristics required for entry (Kemp et al. 2007; Meadowcroft 2009a; Mitchell 2015; European Commission 2016; Kominers et al. 2017; Leslie et al. 2020). In these ways, market rules influence both the speed and direction of electricity transition pathways.

The legacy of a centralised, top down electricity system in GB has led to an electricity market design in which the rules are well-suited to the characteristics of conventional forms of generation, but often not those of the newer technologies, nor the recent emergence of an active demand side[1] (Table 1). A market design which is designed to provide revenue to fossil fuel generators will likely encourage the continued use of fossil fuels, often at the expense of allocating revenue streams to renewable generators and the demand side. The current market has also been set up with a supply-focused architecture which risks failing to utilise new developments on the demand side (such as load shifting or storage). The market design determines how revenues can be accessed and therefore which business models are viable; in turn, the business models adopted will shape business plans and investment. As the technologies change and the system transforms, it is important that the market design is updated so as not to hold back positive change.

As the value setter, achieving the UK's net zero commitments of decarbonising the power sector by 2035 will depend upon the rules of the electricity market design (CCC 2020; BEIS 2021a). As long as fossil fuel technologies remain profitable, in part because of the current set up of the electricity market design rules and not least through direct support in the form of revenue assurance schemes, then they will continue to be built. This will jeopardize the achievement of climate objectives (IEA 2021).

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[1] The demand side within this context refers to the end consumers (e.g. households) who are able to interact with the electricity system. An example of such interactions could be the shifting of electricity demand. These actions are usually financially incentivised.

1.2 The role of the electricity market design and the increasing cost of living

At the time of writing, British households are facing an increased cost of living in part stemming from the rising price of energy. A fit for purpose electricity market design can help mitigate some of these charges.

As a result of the UK's reliance on international commodity markets to secure fossil fuels, primarily gas, the volatile nature of these markets impact the cost of living. Firstly, gas plants provide the majority of electricity within GB (Figure 1) and therefore the international price for gas is reflected in the costs incurred by energy suppliers to provide generation to their customers. As such, the record-breaking prices for gas[1] which many suppliers did not hedge against and a price cap on how much a supplier can charge to their end consumers has led to many suppliers going into administration as they are unable to recover the costs of securing gas supplies. This cost of gas has been reflected in Ofgem's price cap review, leading to a 54% increase in the cap itself which equates to almost a £700 rise per annum on a domestic property bill which will come into force in April 2022 (Ofgem 2022). This is expected to drive millions of households into fuel poverty (The Guardian 2022). Secondly, the rising cost of energy is also fuelling a growth in inflation as businesses will also need to absorb this cost, which will be passed onto consumer. As of February 2022, inflation is at a 30 year high at 5.4%, with the Bank of England forecasting this to rise by 7.25% by April of the same year (BBC 2022; The Guardian 2022). GB's reliance on the international commodities market has been recognised by Government to be unsustainable, and was a key contributor to the UK's 2021 announcement to decarbonise the power system by 2035 (BEIS 2021a).

As will be argued throughout this thesis, GB's electricity market design should be augmented. Doing so would reduce reliance on these international markets through incentivising the utilisation of existing and future domestic technologies and an increasingly active demand side. By getting the energy economics correct, future investment into these domestic technologies and service providers will be encouraged.

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[1] Since Q2 of 2021, the cost of gas has reached historic highs.

In short, British households are facing an increase to the cost of living and a fit for purpose electricity market design can aid to reduce these charges relating to the international power markets. The proposed market design will also aid to meet the power sectors' decarbonisation target, empower the demand side and encourage an energy efficient use of the networks. This underpins the importance of undertaking research into this topic.

1.3 The requirements of GB's electricity market design have changed

The GB electricity system is undergoing fundamental change, transitioning from a top down, unidirectional system dominated by large, centralised thermal generators supplying passive consumers. The system that is emerging is increasingly decentralised in which generation is provided by a diverse source of VRE generators across the network and travels in all directions. As recently as 2010, over 75% of electricity generated within the UK stemmed from fossil fuel sources with only 7% coming from renewables. By 2020, renewables made up over 42% of the electricity generated in the UK, outstripping fossil fuels for the first time (Figure 1) (BEIS 2020a, 2021c). The decline of fossil fuel contributions to GB's electricity production are expected to continue. All National Grid ESO's Future Energy Scenarios (FES) forecast a reduction in generation from these synchronous generators, with their 'Leading the Way' scenario forecasting a fall by over 85% between 2020 and 2035 (National Grid ESO 2020a). Within this emerging system, consumers can play an increasingly active role (Mitchell 2016a; NIC 2016). A consequence of this shift is a change in the characteristics of the electricity system, as summarised in Table 1.

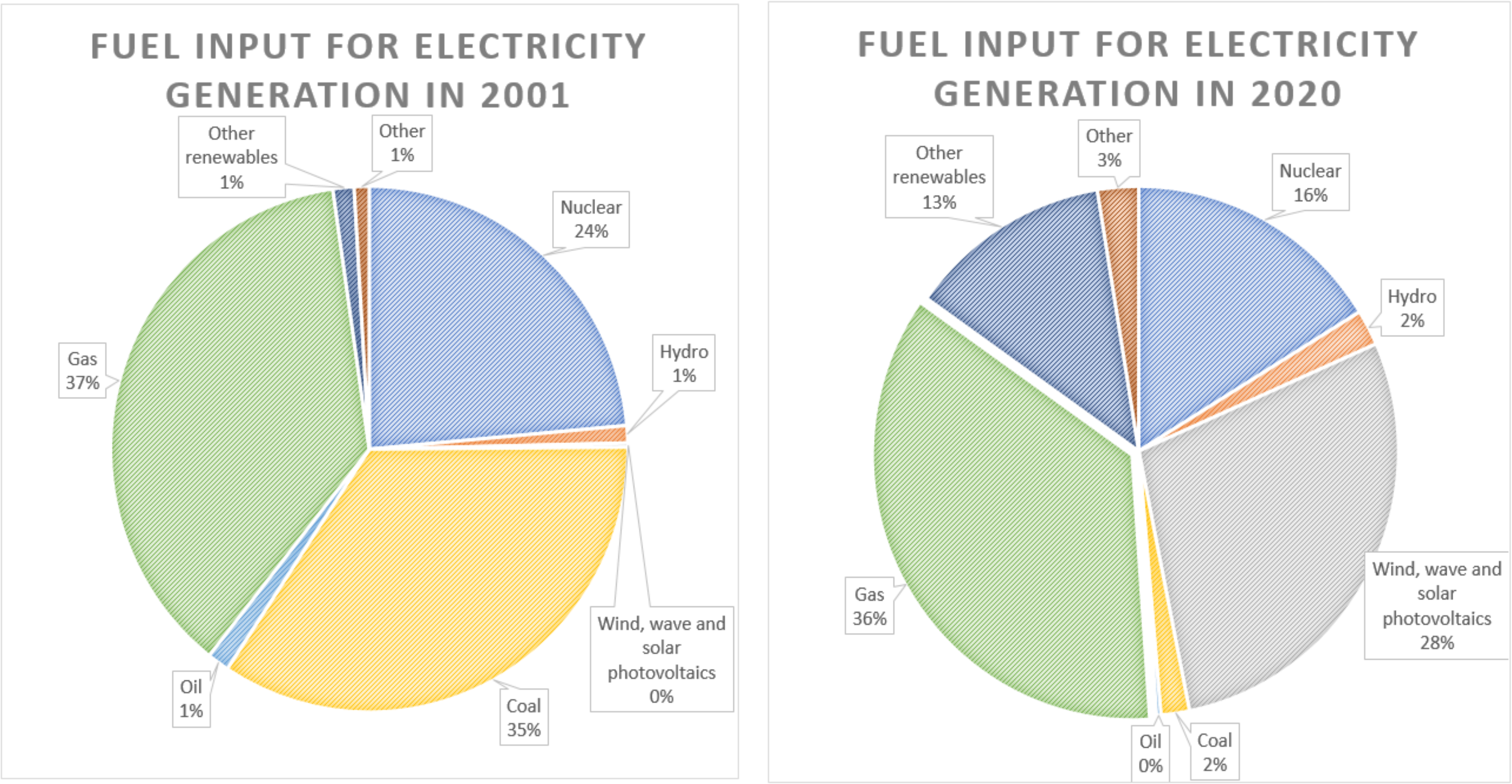
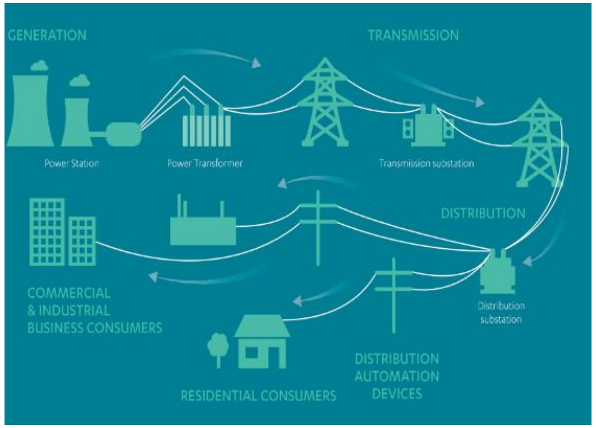
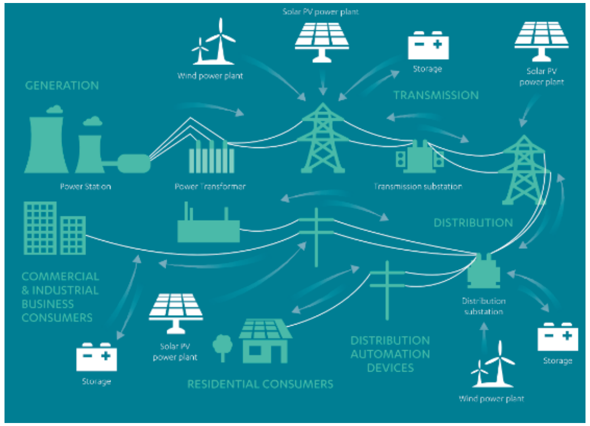


Figure 1 Left: The fuel input for electricity generated in 2001. This provides a snapshot of the technologies which generated electricity at the time of an electricity market re-design in GB, known as NETA (to be discussed in chapter two, section 2.1.1). Right: The fuel input for electricity generated in 2020 highlighting the changing electricity landscape with the rapid growth of renewable forms of generation at the expense of phasing out coal units. The contributing fuel inputs for 'Other renewables' includes bioenergy. This trends has been attributed to a combination of policy directives in response to anthropogenic climate change and technological innovation (Mathews 2013; Kern et al. 2014; Markard 2018; BEIS 2020e). *Data source:* (BEIS 2021g).

Table 1 A comparison of several characteristics present in the 20th century electricity system and that of the 21st. Image Source: (NIC 2016).

	20th century electricity system	21st century electricity system
		
Geography	Centralised.	Increasingly decentralised.
Fuel source(s)	Fossil fuel and nuclear.	Renewable and low carbon.
Operational logic	Load following.	Supply and demand resources offering services.
Generation characteristics	Firm powered.	VRE power with increased requirement of flexibility.
Governance	Top-down operation.	Operation at multiple localities.
Flow of generation	One-way flow of electricity.	Two-way power flows.
Role of end consumers	Consumers considered passive.	Spectrum of consumer behaviour.
Treatment of energy silos (between heat, mobility and electricity)	Treated as separate entities.	Breaking down these tradional silo's.
Proximity between generation and load	Electricity generated distant from load.	Generations increasingly close to load.
Stakeholder profiles	Stakeholders mainly operating from within this sector e.g. energy suppliers.	Multiple stakeholders- data, IT, car manufactures for example.

This transition has been driven by four key trends: decarbonisation, decentralisation, digitalisation and democratisation, the ‘4Ds’ (Table 2) (Soutar 2021).

These trends are shifting GB’s electricity sector from a predominantly centralised, top-down and linear model to one which contains a mixture of both centralised and distributed technologies (NIC 2016; HM Government 2020a; National Grid ESO 2020a; Papalexopoulos et al. 2020). Pursuing a decentralised electricity system brings forward a host of benefits which cannot be realised under a fully centralised alternative. These include empowering passive consumers and rewarding them for providing services to the network.

It is unlikely that GB’s electricity system will remain fully centralised or transition to a fully decentralised system, but will comprise a mix of the two (NIC 2016; HM Government 2020a). For example, National Grid Electricity System Operator (ESO)’s 2020 FES forecasts that by 2050, 42% of capacity will be connected to the distribution network (National Grid ESO 2020a). However, any centralised unit that is deployed on the network must not rely on fossil fuels (CCC 2019, 2021).

Table 2 Description and Examples of each of the 4Ds. Source: (CCC 2017; Future 2017; PowerGen 2017; Soutar and Mitchell 2018; HM Government 2020a; Soutar 2021).

The 4Ds	**Description**	**Example**
Decentralisation	In this thesis, decentralised refers to the deployment of small-scale generating technologies and the ability for end consumers to provide grid services, moving away from the historically centralised energy system.	Recent estimates are that there are over 1,100,000 solar photovoltaics (PV) installations dispersed across the UK – often at point of use, a large increase from when the system was fully centralised (BEIS 2021d).
Digitalisation	Considered as the rapid transition towards increasing the use of digital and data-based technologies (Judson et al. 2020).	Through changes to software and data processing practices, digitalisation allows data to be collected in more granular units and closer to real time aiding the forecasting and control of energy assets (Judson et al. 2020).
Decarbonisation	The reduction of GHG stemming from the generation of energy within the context of this thesis.	The phasing out of fossil fuelled technologies with zero carbon alternatives.
Democratisation	Defined by Szulecki (2018) as a conceptual decision making tool consisting of three key dimensions; popular sovereignty, participatory governance and civic ownership. In broader terms, Stirling (2014) argues that progressive energy transformations can challenge the existing and entrenched regime interests, opening up for a more democratic means of operating the energy system.	Impacts from the aforementioned three-Ds has reduced the barriers for small-scale actors, such as prosumers, to invest and benefit from VRE deployment (Szulecki 2018). This has provided agency for such actors to engage and influence the wider energy system, as opposed to being price-takers with incumbents dominating this landscape.

In parallel to the deployment of distributed energy resources (DER) such as small-scale solar and onshore wind, the expansion of the Internet of Things (IoT), data collection and analytics and the development of private third party operated platforms, has the potential to unlock distributed demand and supply flexibility from the once passive demand side (BEIS and Ofgem 2017; Zhang et al. 2018; Papalexopoulos et al. 2020). This brings the possibility of trading electricity and ancillary services at the local level, which have been both proposed within the academic literature (Gerard et al. 2018; Papalexopoulos et al. 2020) and is being demonstrated in reality. For example, UK Power Networks' (UKPN) Power Potential programme is utilising DER to resolve transmission voltage and thermal constraints on their networks (National Grid and UKPN 2017; National Grid ESO 2018a, 2020b).

As the characteristics of the electricity system change, so too must the electricity market design to incorporate these new traits. Failure to do so will lead to a continuation of the rules which suit fossil fuel-based generation and will hinder GB's progress towards a net zero power sector. As such, it is essential to implement a re-design of this institution (Grubler 2012; Mitchell 2015; Ford and Hardy 2020). However, redesigning GB's electricity market design is not a simple task. There are major implications which will emerge from altering the rights, rules and responsibilities enshrined in markets, not least re-distribute access to value, creating winners and losers in doing so (Kemp et al. 2007; Meadowcroft 2009b; Mitchell 2015).

Furthermore, this re-distribution of access to value will impact the speed of the energy system transition. Through providing value for specific services, such as the provision of generation from low-carbon sources, can incentivise investment in the short term into the technologies which meet the criteria to access this potential revenue stream. This can be exemplified by the Contracts for Difference (CfD) mechanism introduced by the UK Government in 2014 to bring forward investment into low-carbon generation[1]. In April 2017, 346MW of offshore wind had been installed under a CfD, whereas in November 2021 this has increased sevenfold to 3,405MW (LCCC 2021). This demonstrates that the electricity market design, and where value is assigned, will impact the speed of the transition as has been shown in this example with the deployment of offshore wind. Therefore, an electricity market design can either enable, or constrain

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[1] More details on this scheme will be introduced in chapter two, section 2.2.1.6.

the progress of the electricity system towards a specific policy objective, such as a 2035 net zero power sector. As such, rigorous research is therefore required into an electricity market design which is fit for purpose prior to its implementation. This thesis will provide the blueprints for an alternative electricity market design for GB in relation to the design and governance of this institution. The current electricity market design within GB is no longer fit for purpose

To achieve a net zero power sector by 2035, the majority of carbon intensive generation must be phased out and replaced with zero carbon alternatives, such as VRE, and the demand side must be better utilised through the provision of demand-side flexibility and generation. Zero carbon electricity generation technologies are proven and cost-competitive, however, deployment is hindered by the institutional governance of the electricity sector which is not acceptable (Willis et al. 2019a).

In order to realise the opportunities stemming from an increasingly decentralised electricity system, the institutional governance must be fit for purpose[1] (Mitchell 2015; Lockwood et al. 2019a; Willis et al. 2019a). The governance arrangements of the electricity system are stalling the transition to a high renewable and cost effective future (Mitchell 2017a; Willis et al. 2019a). Governance for net zero in relation to decarbonising the energy sector requires changes to the institutional framework; these include new duties for current regulators, designing and implementing more appropriate policies and increased devolution of energy governance to local levels, and the reconfiguration of GB's electricity market design to be suitable given the changing wider electricity landscape (Chilvers et al. 2017; Willis et al. 2019a; Ford and Hardy 2020).

The electricity market design is therefore one part of the broader electricity system, but the design of this institution will in turn influence how the wider sector operates. It is therefore paramount that the electricity market design is appropriate, and the incentives which come from this institution enable new means of system operation which reflect current and future goals; for example, decarbonisation, system security and fairness for end consumer fairness, all at least cost.

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[1] The term 'fit for purpose' is subjective. Different stakeholders of the electricity market design will have their own views on what this term means in relation to the electricity market design. This term will therefore be explored within section 1.5.1.

1.4 Clarifying terms

Throughout this thesis there will be reference to 'institutions' and 'organisations'. These are terms which have often been used interchangeably despite their cited differences. To differentiate these terms within this thesis, the seminal work of North (1990) will be used to provide the definition of an institution, which he defines as the formal and informal rules of the game, and it is within these institutions that actors make decisions. This thesis meanwhile refers to organisations as collective groups of individuals with a particular purpose which could be governmental - such as the Department for Business, Energy and Industrial Strategy (BEIS) - or non-governmental - such as the Low Carbon Contracts Company (LCCC). Institutions and organisations interact in that the actions that organisations are able to take will be constrained or enabled by their institutional environments (North 1990).

The terms 'market', 'electricity market' and 'market design' are frequently used by analysts and others interchangeably but are conceptually distinct. This is a consequence of the terms 'market', 'market design' and 'electricity market' evoking different interpretations depending on one's perspective and involvement with either a market or the market design (Turnheim et al. 2015; Harrison and Kjellberg 2016). It is necessary to define what is meant by 'market', 'electricity market' and 'electricity market design[1]' within this study.

For the purpose of this study, a market is understood as a socially-constructed interface, designed by relevant parties to facilitate specific goals and outcomes, by which the exchange of well-defined goods and services between parties can occur repeatedly (Kominers et al. 2017; Roth 2018). The work of Fligstein and Dauter (2007), Caliskan and Callon (2010) and Kominers et al. (2017) characterise this social structure as involving relations between competitors, suppliers, customers and government. Markets are thus the spaces in which confrontation and power struggles between market participants emerge (Caliskan and Callon 2010). An electricity market is, by extension, the interface which permits the buying and selling of units of electricity and ancillary services. In practice, this is carried out through various mediums, such as the Nordpool portal in which members can purchase and sell, online websites such as the

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[1] This thesis will draw upon the definition provided in section 1.6.

intercontinental exchange (ICE) or Trayport, which allows trading via interfaces with the local energy market (LEM) and access to the balancing mechanisms and other ancillary services procured by National Grid ESO. As defined, one may expect that this institution would drive optimal investment through adequate short- and long-term pricing signals. However, as will be shown within Chapter two, this is not the case for GB's electricity market design.

Ideally, the electricity market design itself would be sufficient to unlock the investment required into the service providers that underpin GB's net zero ambitions. That said, there is clear evidence that will be introduced within this thesis that this is not the case. Bespoke policy instruments may therefore be required for innovative business models, e.g., a transmission connected battery unit. Yet to underpin a significant proportion of the service providers operating within GB under a policy instrument would dilute the significance of the market design itself and revenue streams become less reliant on this. This debate is outside of the scope of this thesis, as will be discussed in section 1.8, but given the reality of unlocking large levels of investment from an increasingly CAPEX reliant set of technologies, policy instruments may be required to complement the investment signals provided by the market design itself.

Electricity market designs across different countries will share similarities and differences (Correljé and De Vries 2008). For example, there may be similarities in the role of the market design to implement rules which permit the coordination of market participants through the setting of standards and expectations on how trade is to be conducted.

Yet, market designs will differ due to the characteristics of the products being traded. This is true for the electricity market design which facilitates the trade of electricity as a product with its own unique characteristics which therefore requires bespoke arrangements. These unique characteristics of electricity include (Cramton 2017):

1. Electricity cannot feasibly be stored in large quantities
2. Demand and supply needs to be constantly synchronised
3. Flows of electricity are bound by the physical networks across which they flow

Furthermore, secure supplies of electricity are vital to modern day society and as such the electricity market design is subjected to various governmental policies to ensure that the nation in question has a secure supply of electricity.

When considering other 'market designs' found within the academic literature, such as those identified by Roth (2015, 2018; 2019) work on market design which includes the design of medical labour markets, the auctions of radio spectrums and the allocation of prospective students to schools, it is clear that there are many market designs out there. The electricity market design is tailored to suit the characteristics listed above, but there will likely be similarities in the process of the evolution of this and other markets. For example, the influence of vested interests leading to the resistance against the implementation of a market re-design which goes against the status quo (Pierson 2000; Unruh 2000; Hall 2010; Scott 2013; Moe 2016). Therefore, there will be similarities, but as for reasons stated above, differences as well, which will emerge when considering the evolution of this institution.

As such, understanding this process of institutional change can be aided by the incorporation of an established theoretical framework to understand this process, situate the process of market re-design within the broader literature and build upon an already established framework to understand this process (Sacred Heart University 2006; Grant and Osanloo 2014; Stewart and Klein 2016).

1.5 Aims and research questions

The aim of this thesis is to understand, within the context of the GB electricity sector, the notion of developing and implementing 'a fit for purpose electricity market design'. This phrase can be explored by unpacking this term into three constituent parts:

Part one: Evidencing how the current market design is no longer fit for purpose in GB.

Part two: Exploring solutions to part one, i.e. how the GB electricity market design can be made fit for purpose. Critiquing the current design and bringing forward an alternative proposal.

Part three: Exploring the process of electricity market re-design to facilitate the institutional evolution required to introduce the proposed 'fit for purpose' electricity market design for GB. Part one and two focus on electricity market design as a noun in terms of how a market is designed and fits together within the wider institutional framework. Part three thinks of 'market re-design' as a verb, as the process of getting from the current market design to one which is fit for purpose.

In structuring the research questions around the notion of implementing a fit for purpose electricity market design in GB, there are three research questions which can be framed in terms of the problem (RQ1), the solution (RQ2) and how we might get there (RQ3).

RQ1: In what ways is the electricity market design in Great Britain no longer fit for purpose?

RQ2: What does a fit for purpose electricity market design for Great Britain look like?

RQ3: What recommendations to policymakers can be identified to aid the process of contemporary electricity market re-design?

1.6 What is meant by a 'fit for purpose' electricity market design in the GB context?

The notion of 'fit for purpose' centres on the identification of the 'purpose' of the institution under study, and how well suited (or 'fit') it is for this designated purpose. The purpose of an institution such as the electricity market design is explored in the following chapter, but, in summary, it consists of achieving four objectives:

- Efficient dispatch: Is the lowest cost resource being activated to meet demand?
- Adequate capacity: Is there enough capacity to meet demand?
- Optimal investment: Is the lowest possible cost resource built to meet demand?
- Net zero compliance: Do the rules of this institution aid in the facilitation of net zero in the context of decarbonising the electricity sector within GB?

It is the fulfilment of these objectives which will determine the efficacy of GB's electricity market design.

These objectives are not stationary, but evolve over time, and therefore whether a new electricity market design remains to be 'fit for purpose' will shift over time. In this light, the electricity market design itself can be considered a policy tool to aid in the achievement of certain goals, whilst the goals of government can in turn influence the electricity market design (Bjørn 2017; Gencer et al. 2020).

This relationship between the shifting energy policy goals within GB and subsequent changes to the electricity market design to facilitate these goals can be evidenced through building upon the work of Kern et al. (2014).

Kern et al. (2014) asserts that UK energy policy underwent a paradigm shift between 2000 and 2011. Objectives within this sector shifted from prioritising the provision of a secure sustainable supply of energy at competitive prices through a free electricity market, to placing a higher emphasis on the facilitation of energy security, sustainability (in terms of reduced carbon) and increased levels of VRE (Kern et al. 2014).

These findings have been placed into Table 3 which also summarises the two electricity market re-designs which occurred in the subsequent years. This highlights how the policy objectives of the energy sector have been subsequently reflected in the market re-design processes.

Table 3 The objectives of the energy policy paradigm in 2000 and 2011 and the impact of electricity market re-design which occurred around that time. Policy objectives for the years 2000 and 2011 taken from Kern et al. (2014) with the alterations within GB's electricity market design made to facilitate these objectives provided by the author.

	2000 (pre-NETA)	NETA (2001)	2011 (pre-Energy market reform (EMR))	EMR (2014)	Net zero (2019)
Objectives of policy	The provision of secure, diverse and sustainable supplies of energy at competitive prices as an outcome of freely trading, competitive markets.	No central dispatcher, free trading of electricity Bilateral trading arrangements to aid in keeping coal on the grid i.e. diversification of energy sources.	Energy security, including affordability, one of two primary objectives. Climate change mitigation goals now legally binding through climate change act (and specific to include precise level of emissions reductions). Increasing share of renewable energy now formal objective of policy. Affordability objectives somewhat side-lined.	Energy security: capacity market. Climate change: Carbon price. Deployment of Low carbon technologies via the CfD, e.g., Offshore wind and nuclear Affordability side-lined: High costs associated with policies placed onto end consumer bills.	Policies for net zero

This exemplifies a relationship between current policy objectives of the energy sector within the UK and how the electricity market design during subsequent re-designs has catered to these objectives. The introduction of a new objective, namely a net zero electricity system, therefore, provides further justification for this institution to undergo a re-design to become fit for purpose. This also suggests that a change to energy policy is one facet which contributes to implementing a new electricity market design. This thesis explores other contributing factors which underpin implementing a process of institutional change in the context of the GB electricity market design.

1.7 The boundary of this thesis

The electricity market design is one part of the broader institutional framework of the electricity sector; it is embedded within macro-level policies, such as energy security policy, and interacts with the design and implementation of micro-level policy instruments (Geels 2002; Peng and Poudineh 2017; Willis et al. 2019a). There are many different facets to the electricity market design which depend upon the lens on the researcher. Chapter one thus far has detailed what is to be expected from this thesis. The following list details aspects which will not be explored within this thesis:

1. Propose specific products that should be procured through the electricity market, e.g. new ancillary products such as reactive power services.
2. Discuss the reform of network charging. Electricity market design and network charging are inherently interlinked and can be used in conjunction with each other to achieve intended outcomes. Networks are natural monopolies and are regulated as such. The choices that participants operating within the electricity market design make are inherently directed by regulation, such as the governing practices of the network (IEA 2016; De Vries and Verzijlbergh 2018; Stanley et al. 2019). The regulation of the networks play an important role in the integration of VRE, flexibility as a service, and new technologies and the regulation must therefore be coordinated with the investment in generation and development of flexibility services in the market (De Vries and Verzijlbergh 2018; Stanley et al. 2019). Network regulation is clearly an important facet of how the electricity system operates, and there are arguments that the current regime is outdated and must be re-design (Mitchell and Hardy 2021). The topic of holistic electricity network regulatory re-design is outside

the scope of this thesis. That said, the thesis will present options for network regulatory re-design when there is a clear overlap between these two topics i.e., how amending aspects of network regulation can aid in facilitating the outcomes of the proposed electricity market design.

3. Provide a robust preference of the long-term investment contracts (both current and future). The focus of this thesis is not primarily focused on the re-design of these policy measures, but rather the operational timeframes i.e., from 48 hours in advance to real time. The rationale, as will be shown throughout this thesis, is that these short-term markets are paramount to both operational decisions and underpinning the investment case for the service providers which must be present within a zero-carbon electricity sector. These signals will then feed into the long-term investment contracts which themselves merit further research. That said, there is clear merit in discussing the current state of these contracts, the impacts these are having on the efficacy of GB's electricity market design and the ongoing policy debates on possible alternatives. This is because such debates further emphasise the rational for electricity market re-design. For those readers interested in possible alternatives, please review Appendix six, section nine, which provides a summary of several alternative policy measures to aid in unlocking the necessary finance.
4. Discuss the re-design of financial products used within the forward markets, e.g., the design of derivatives and how these are traded (e.g. options, swaps and futures). The focus of this thesis is thus on the shorter-term markets, due to the importance of these timescales for the operation of variable technologies and flexible resource providers. Key findings

Addressing these three research questions, this thesis has identified several key findings.

In addressing RQ1, the following key findings emerge:

1. There are a multitude of issues stemming from GB's current electricity market design being 'outdated'. The last major reform to this institution was in 2004 through the British Electricity Trading and Transmission Arrangements (BETTA)[1], with minor

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[1] The EMR is not considered to be a major reform due to the addition of new market mechanisms, rather than re-structuring the fundamentals of this institution as was the case with NETA. That said, it must be

additions or changes since; yet, the electricity system in GB, and indeed across the globe, are undergoing a fundamental shift. The characteristics and the economics of the current and emerging electricity system are ill-suited to the market design rules set up over a decade ago. This provides the impetus to explore alternative electricity market design arrangements for GB which are suited to an electricity system underpinned by VRE and an active demand side.

In addressing RQ2, a ‘fit for purpose’ electricity market design is proposed:

1. The design proposed here focuses on the various marketplaces which constitutes GB’s electricity market design, within the 48 hours up to real time, and on the coordination between these different marketplaces. The design has been validated and appraised through various means, such as through 41 industry expert interviews, presenting to both national and international audiences, and academic peer-review and publication which can be found in appendix seven (Pownall et al. 2021).

In addressing RQ3 there are three key findings for policymakers and academics:

1. For policymakers the findings detailed in chapter seven identify the barriers facing contemporary electricity market re-design in GB. This chapter then proposes several means to overcome these, inferred from the theoretical framework proposed in chapter three, insights gathered by a review of the literature and the analysis of interview transcripts. Arguments for enacting this institutional change all at once, akin to NETA, compared to incremental adjustments is justified due to the breadth of augmentations required and the timescale to do so. This provides evidence to policymakers on why such a course of action is required.
2. For academics the use of both historical and discursive institutionalism is shown to provide the necessary tools to critique the process of electricity market design in an advanced economy, justifying it’s use in future study. These will be discussed in depth within Chapter three, but in short, the former focuses on the formal and

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recognised that from a low-carbon lens, the EMR and the policies it introduced has led to major investments into low and zero carbon technologies. Therefore, whilst the EMR may not be considered a major reform to GB’s electricity market design when compared to the fundamental changes that NETA introduced, from a low carbon lens the EMR did have a significant impact on the operation of GB’s electricity market.

informal rules that structures impose and the role of agency within this. The latter focuses on the important of ideas in explaining institutional change.

3. Policymakers will also benefit from these insights which provide guidelines on how the process of contemporary electricity market re-design must occur. These insights are necessary to utilise the innovations stemming from the increasingly diverse pool of market participants and their experiences.

1.8 Structure of this thesis

Chapter two: Great Britain's electricity market design

Chapter two begins by reflecting on the government's appetite for the use of markets, stemming from the privatisation of the electricity and supply industry during Thatcher's privatisation era. A brief history of the market arrangements within GB is provided before going into more depth on how the current electricity market design operates. The efficacy of this institution is reviewed, based upon the facilitation of the three main objectives; efficient dispatch, adequate capacity, and optimal investment, and argues that a fourth objective of facilitating net zero must underpin these and intensifies pressure on the need to re-design the electricity market design.

Chapter three: Theoretical perspectives on electricity market re-design

Chapter three begins with a reflection on the importance of theory before exploring how electricity market re-design within GB occurs in practice. This provides the focus to which the proposed theoretical framework can be applied to in order to assess its applicability. This is followed by an overview of the potential theoretical frameworks which could offer insights into the process of electricity market re-design. This section concludes that a combination of historical and discursive institutionalism offers an appropriate lens to study the phenomenon of institutional change in the context of GB's electricity market design.

Chapter four: Methodology

Chapter four details the methodological approach used to answer the aims and research questions of this thesis. This begins with a summary of the various means of data collection before detailing the creation, appraisal and validation of the strawperson electricity market design. This chapter then reviews how the data was analysed to provide the findings for the following chapters.

Chapter five: Issues with GB's electricity market design, alternative proposals and the scale of alterations required.

Chapter five begins with an overview of the various concerns regarding the GB electricity market design as identified by a combination of a review of academic, industry and governmental literature and discussions with key stakeholders. This leads into a review of 49 papers with proposals for electricity market reform which provided potential solutions to these issues; elements of these proposals provide the foundation for the proposed solution in chapter six.

Chapter six: The thesis's proposed electricity market design

Chapter six introduces the proposed electricity market design for GB. This begins with a short summary of the organisations which underpin the functioning of the electricity market design. The design is then introduced. This is accompanied by appendix six which provides the rationale for the decisions made when there were trade-offs, e.g., whether to have the electricity market design based on uniform, zonal, or nodal[1] pricing. How the design meets the criteria of being 'fit for purpose' is then justified.

Chapter seven: Lessons on implementing contemporary electricity market re-design

Chapter seven utilises the theoretical framework developed in chapter three to explore the barriers to contemporary electricity market re-design in GB and also identifies solutions for policymakers. This is followed by a discussion on how the process of electricity market re-design should occur within GB, arguing that an implementation akin to NETA would be the preferred option compared to the current trajectory of making incremental adjustments. The third section of this chapter focuses on the need for political will to underpin this transition to a net zero electricity market design in GB, why this may not be forthcoming and means to overcome this.

Chapter eight: concluding remarks and future avenues for research

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[1] Also known as Locational Marginal Pricing (LMP).

Chapter eight concludes this thesis. This begins with a reflection on how each of the research questions have been addressed before discussing limitations of the study and avenues for future research. The policy implications and academic contribution are then provided before a final reflection.

2.0 GB's electricity market design

This chapter begins with a review of the UK's government's appetite for market-based solutions compared to centrally organised alternatives in terms of how electricity can be bought and sold. This is briefly followed by a summary of the trading arrangements brought in at the time of privatisation as well as the superseding arrangements which provide the foundations of electricity trading in operation within GB today. This chapter then reviews the key objectives of this institution, and to what degree these are being met.

2.1 Government's appetite for markets and the introduction of the Pool

In a review of electricity markets across the globe, Correljé and De Vries (2008) highlight the variety of market arrangements employed by nations as a means to facilitate the trade of electricity. These range from state-run programmes, a move to privatisation and the use of markets, or a hybrid of the two with both state and markets operating in co-ordination.

Within the context of GB, there is a value placed on markets as the means to facilitate the trading of electricity (Mitchell 2008). This fits into the broader ideology of privatisation, with the decision to privatise the electricity sector being attributed to the principles of the Conservative government whose manifesto for the 1979 general election pledged to privatise specific industries (Conservative Party 1979). The programme of privatisation reforms expanded post-1983 with major utility companies such as British Telecom (BT) and British Gas being privatised in 1984 and 1986 respectively (House of Commons 2014). The Electricity Act 1989 laid the legislative foundations for the privatisation of the electricity industry within GB (Simmonds et al. 2002; House of Commons 2014).

A variety of motivations have been identified for the UK choosing to privatise several previously public sectors. A House of Commons research paper on this topic identifies three motivations for privatisation (House of Commons 2014). First, the transfer of responsibility to the private sector, in return for Government financial commitments, raised money for the public purse and an expectation of future savings for the Government which no longer viewed that particular industry as a financial burden. Second, the belief that being run under private ownership would make any industry more efficient. Finally, increasing the spread of share ownership was seen as a means to encourage an entrepreneurial society with share owners becoming actively engaged.

The suite of privatisation reforms brought in under Thatcher's government demonstrates an appetite for markets to provide solutions, such as the efficient delivery of electricity.

This appetite for the liberalisation of the electricity supply industry can also be witnessed on the European continent, with the European Commission legislating the Electricity Directive 96/92/EC and Gas Directive 98/30/EC which were adopted in 1996 and 1998, respectively (European Commission 1996; Newbery 2002). Central to this liberalisation drive was the EC's argument that "market forces produce a better allocation or resources and greater effectiveness in the supply of services" (European Commission 1996: 3).

Indeed, the liberalisation of the electricity supply industry is cited as providing a variety of efficiency advantages over government controlled alternatives. These include improved means for coordination of resources, competition driving innovation and performance at minimal operation costs, and transparency of prices aiding future investment decisions by third parties as these provide a refernence price to base future investments upon (Newbery 2002; Ringel 2003; IEA 2016). As electricity is considered a homogenous product (i.e. there is no perceived difference in the product – a kilowatt-hour (kWh) is a kWh regardless of the source in terms of powering appliances) product differentiation largely stems from price comparison between service providers (Ringel 2003).

The new market arrangements established at the time of privatisation, the Pool, facilitated the trade of electicity in England and Wales post privatisation (Ofgem 2002; Simmonds et al. 2002; NAO 2003). This thesis will not discuss the wider politics surrounding the introduction of this mechanism, but will summarise how the Pool itself functioned as a market.

The 1989 Energy Act liberalised the electricity sector shifting from a state monopoly to a private market-driven system (Legislation.gov.uk 1989; Newbery and Pollitt 1997; Newbery 2005). The Central Electricity Generating Board (CEGB)[1] was disbanded and the role of scheduling the dispatch of electricity was fulfilled by the introduction of a SPOT market in 1990 which functioned through a Pool clearing mechanism (Newbery and Pollitt 1997; Hogan 2002; Newbery 2005). All generators over a certain Megawatt (MW) threshold were required to bid in daily prices representing the fee for their generation. Bids were then stacked in a price-based 'merit order', with the most expensive plant required to meet the demand setting the clearing price which all required generators received (Figure 2) (Newbery and Pollitt 1997; Hogan 2002; Newbery 2005). In short, privatisation introduced competition and trading into a previously monopolised electricity sector (House of Commons 2019).

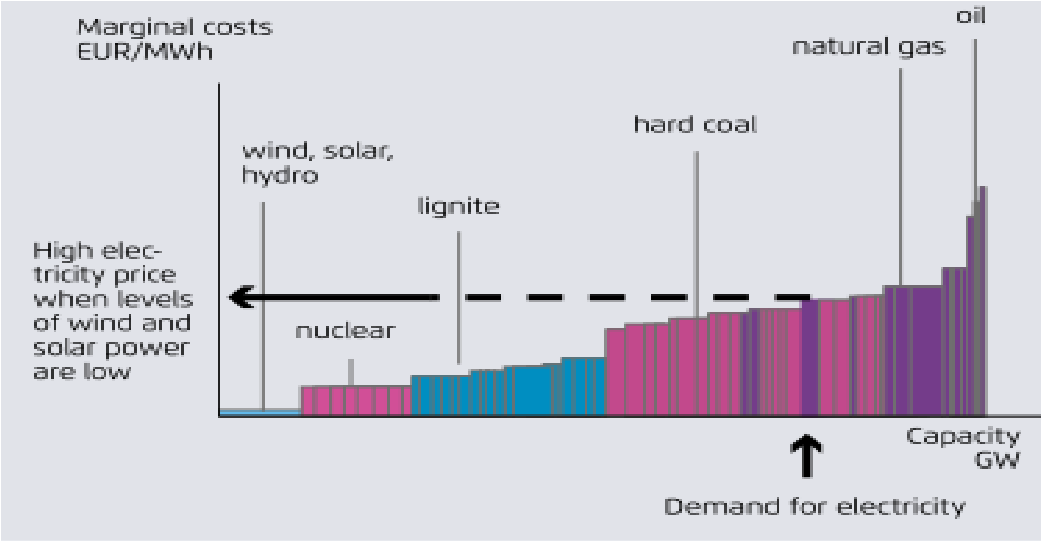

Figure 2 An example of the Merit Order. In this purely illustrative example, each block represents a different generator. All those left of the 'Demand for electricity' are considered to be 'in merit' and the last plant to be in merit, the purple box above the demand for electricity arrow, would set the clearing price which all generators to the left would be paid. Source: (Agora 2013)

Entry to the Pool was effectively open to all generators provided they had signed up to the various codes and licences. For each half hourly settlement period[2], the Pool generated a price for electricity based upon this merit order which all those procuring electricity would pay (Bower 2002; Hogan 2002). The prices generated for each settlement period produced a reference price on which suppliers and generators could

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[1] The predecessor to National Grid. They were responsible for electricity generation, transmission and the bulk sales of electricity in England and Wales.

[2] The Settlement period is defined by Elexon as "A period of 30 minutes beginning on the hour or the half-hour" (Elexon 2021b).

base CfD[1] (Deng and Oren 2006; Redl et al. 2009; ACER 2015). Within these contracts, a certain volume of generation would be bought ahead of real time at a pre-defined price which were influenced by the Pool's clearing prices, as a means to hedge against the risk of volatility in the clearing price (Newbery 2005). It is estimated by Bower (2002) that >90% of output and consumption was traded in the forward markets, signed months or years ahead of actual dispatch.

2.1.1 Succeeding the Pool: The new electricity trading arrangements

Within a decade of privatisation and the introduction of the Pool, the Department for Trade and Industry (DTI) in 1998 began the process of changing trading arrangements again (BEIS 2020b).

The Pool was replaced by a series of bilateral contracts in March 2001, known as the New Electricity Trading Arrangements (NETA) (BEIS 2020b). The products procured within these contracts could be standardised, i.e. baseload and peakload, or tailored to the requirements of the parties involved (Newbery 2005). Bilateral contracts were used to cover the short to long-term positions of those operating in the electricity market. In a similar fashion to operating under the Pool, the majority of trades consisted of long-term bilateral contracts between counterparties as a means to hedge against a volatile price of electricity (Bower 2002). However, these hedging products differed to those procured at the time of the Pool[2]. 48 hours before dispatch, a SPOT market opened to allow parties to adjust their portfolio and contracts to match their predicted physical positions (Newbery 2005). Participants fine-tuned their position in the SPOT market via

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[1] The CfD utilised during the operation of the Pool differs to the CfD introduced by the EMR. During the Pool, a CfD was a decentralised contractual agreement between two parties. A price for electricity would be agreed, known as their 'strike price'. When the pool cleared, any divergence between the strike price and the pool clearing price would be rectified e.g., one party paying the difference to ensure that both parties received the initially agreed upon strike price. The CfD introduced by the EMR shares the same principle of a strike price but is a centralised equivalent as the LCCC is the counterparty, not another market participant. Contract lengths are also set for 15 years to reduce debt financing on new investments.

[2] Under the Pool, forward contracts were restricted to CfDs and exchange-traded forward agreements (EFAs) which were not for physical delivery of electricity but settled in cash as a means of securing financial settlement. Under NETA, most forward contracts are for the physical delivery of electricity rather than financial settlement (Bower 2002).

further bilateral negotiations, or voluntarily traded on an exchange which constructed a SPOT price for each half hour (Newbery 2005).

There are several cited reasons for the transition away from the Pool:

- **Increased wholesale prices**: During the operation of the Pool market from 1990 to 1998, wholesale prices in England and Wales did not decrease and even reportedly increased (Bower 2002). This has been attributed to the concentrated market structure consisting of three major incumbents (National Power, Powergen and Nuclear Electric) limiting competition and maintaining prices even as input fuel costs and capital costs fell, resulting in higher profit margins (NAO 2003; Newbery 2005).
- **Market manipulation**: One outcome of privatisation was the emergence of an oligopoly in which incumbents exercised their market power to artificially raise the payments generators received (Gray et al. 1996; OFFER 1998; NAO 2003).
- **Political support for UK coal industry:** During the 1990s, the market entrance of more efficient Combined Cycle Gas Turbines (CCGT) plants and lower fuel prices (in particular for natural gas) contributed to the displacement and mothballing of coal generating plants (Bower 2002). Green (1999) asserts that the pay-as-clear Pool market structure aided in this displacement as CCGT was able to outcompete coal as the marginal price setter. Green (1999) also speculates that the incoming Labour party in 1997 held sympathetic ties to coal miners and therefore viewed the move from a pay-as-clear Pool structure to bilateral agreements as a means to aid the UK coal industry.

As the majority of generation was procured on a bilateral basis, there was no central operator dispatching generators to meet the forecasted demand; instead a ‘self-dispatch’ model was introduced meaning that each generation company could decide on whether to generate, or purchase from the market to meet their stated contracted position. Unlike the Pool, this did not produce a single reference price, which in turn hindered the ability for smaller market participants to access accurate prices for hedging purposes.

Although NETA witnessed the introduction of the self-dispatch model, there are still exchanges which operate alongside bilateral contracts. These exchanges operate in the SPOT market timeframe and are primarily used to re-position oneself, or to facilitate the trade of electricity from variable generators who are unsure of their output until closer to real time. At Gate Closure[1], the official closure of both the bilateral and exchange operated markets, all parties would provide the System Operator (SO) with two sets of information (Elexon 2017a; House of Commons 2019). The first is the Final Physical Notifications (FPN) to Elexon which states each unit's import or export level which the party expects in a given settlement period (i.e. the expected generation or demand); this identifies whether the party would meet or diverge from their contracted position (Elexon 2017a). Parties would also submit their bid[2] and/or offer[3] data which represented the price that they would want to be paid per MWh for an increase/decrease in generation or demand (Newbery 2005; Elexon 2017a). The SO would then accept bids and offers in order to balance the system (Newbery 2005; Elexon 2017a).

Charging for imbalances was therefore introduced at a time where the dispatch of generation was actively controlled by adjusting fossil fuel input - which is not an assumption for the future electricity system with increasingly variable generation.

2.1.2 A comparison of the Pool and bilateral trading arrangements

A simplistic illustration of trading via an exchange, or trading over the counter (OTC) (also known as trading bilaterally) is provided in Figure 3. The key differences between a Pool and a bilateral system are summarised in Table 4. Trade within GB is predominantly conducted upon a bilateral basis, which in turn reduces the scope of transparency of these trades as only the volume of trade, but not the price, must be supplied to Elexon via an Energy Contract Volume Notification Agent (ECVNA).

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[1] A period of one hour before the start of each settlement period.

[2] **Bids** – A generator/consumer **pays** National Grid ESO for buying more electricity than contracted (either by consuming more or buying the equivalent of their reduced generation).

[3] **Offer** – a generator/consumer is **paid** by National Grid ESO for selling more energy than contracted (either generating more or selling off what they didn't consume).

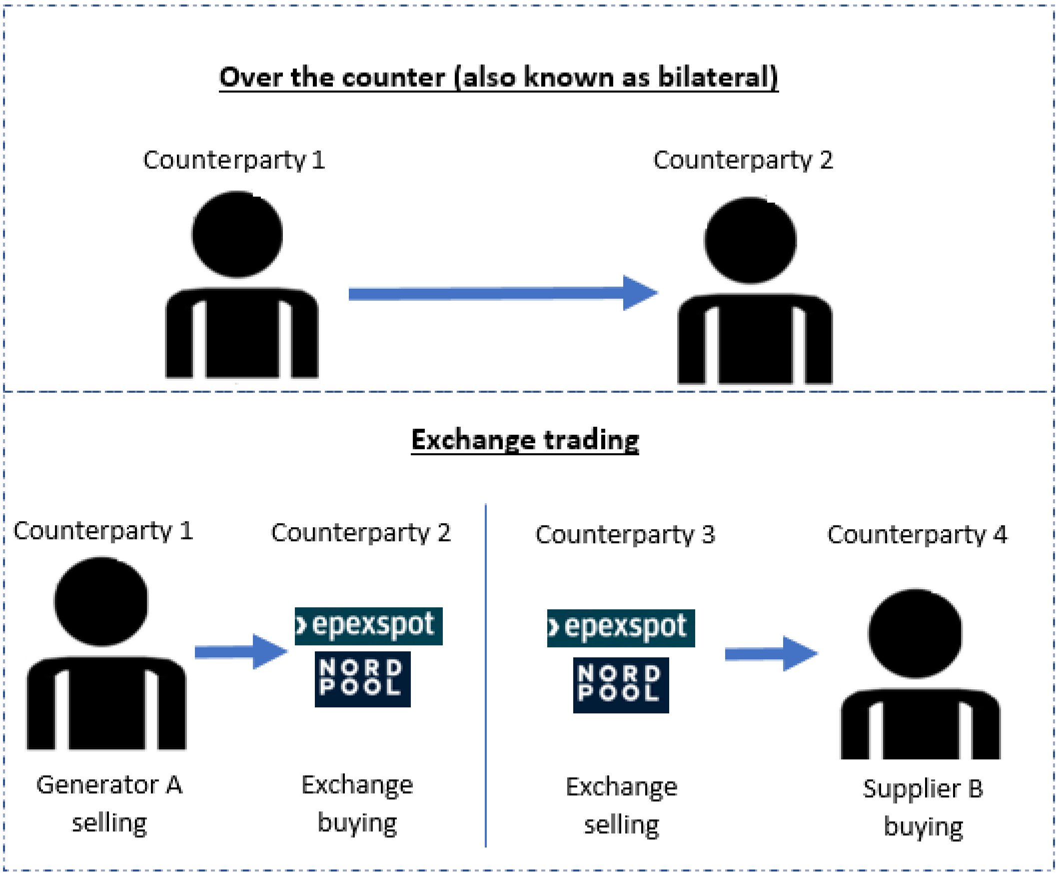

Figure 3 An illustration of the two principle means of facilitating the trade of electricity within GB's wholesale electricity market design.

Table 4 Differences between the Pool and bilateral (OTC) trading arrangements.

	Pool	**Bilateral (OTC)**
Structure	Traded via a central entity.	Contracts set up between market participants.
Scheduling	Central dispatch.	Self-dispatch.
Estimated trades in 2019 (Ofgem 2021a). See Figure 4.	16.4%.	83.6%.
Facilitating trade	A central entity would pool together bids and offers and when supply and demand met a price for each settlement period would be generated. This is a role similar to the exchanges which are in operation within the GB electricity market today, such as N2EX and EXPEXSPOT (Ofgem 2021a).	Often requires a broker, such as ICAP, GFI or Tullet Prebon which pair each counterparty based upon their requirements (Ofgem 2008; GFI 2021; ICAP 2021).
Payment structure	Pay-as-clear.	Determined in negotiations.
Notification to Elexon	Power exchange notifies outcome of trades.	Outcome of contract notified to Elexon via an ECVNA.
Means of conducting trade (BEIS 2016b)	Auctions.	Continuous and/or auctions held by exchanges.
Timeframe	48 hours up to gate closure.	Hours to years in advance of gate closure.
Anonymity	Anonymised.	Can be either anonymous or identified.
Pricing	Cleared price paid by all.	Prices determined bilaterally.

Transparency	High, with prices revealed by each auction (Newbery 2005).	Less transparent[1] price formation due to agreed volumes and prices not being publicly known (Newbery 2005).
Products	Pre-defined products. i.e. 30-minute blocks.	Bespoke in nature. Flexible to the requirements of parties involved (Onaiwu 2010).
Role of SO	The SO[2] creates the merit order based upon bid prices, dispatching the least-cost service (Onaiwu 2010).	The SO is constrained in scheduling by the negotiated contract price and volumes set between the generator and supplier (Onaiwu 2010).
Price volatility	Can be high. Depends upon the level of demand and the cost of the services required to meet this during each settlement period.	As prices and volumes are stated within contracts the exposure to price volatility is lower than in a Pool.
Liquidity	High - due to the convergence of market participants into a single auction (Newbery 2005).	Low – trades are bespoke and market participants are not pooled together (Newbery 2005).
Competition	High – due to increased liquidity as stated above.	Low - as products are procured on a bilateral basis.
Counterparty risk	Low – central exchange takes counterparty risk (Ofgem 2009).	High – no intermediary to cover this risk (Ofgem 2009).

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[1] The loss of transparency is a particularly cogent criticism given that the bilateral trading basis was intended to 'provide transparency'.

[2] Based on the assumption that the SO operates the pool

Cost of trading (credit cover requirements)	Credit must be lodged with the exchange operator i.e. N2EX, though exchanges offer means to reduce the cost of trading (Nordpool 2020).	Parties must have trading, settlement and credit agreements with each counterparty (Cornwall Insight 2018a).

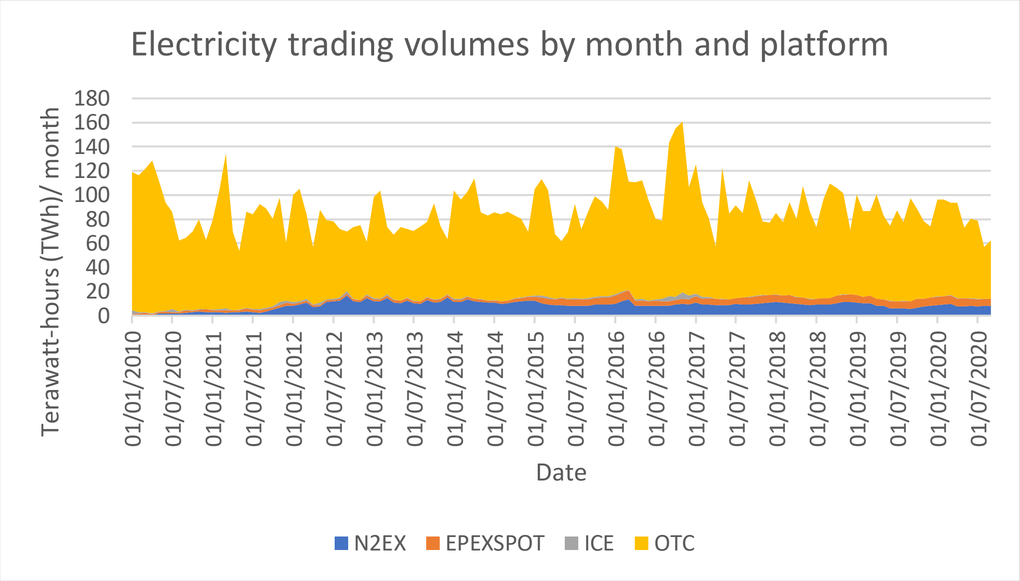

Figure 4 Electricity trading volumes according to data from Ofgem. Though there are three alternative platforms to trading OTC, OTC still dominates the GB marketplace. N2EX, EPEXSPOT and ICE are exchanges. Data source: (Ofgem 2021).

2.2 How does the GB electricity market design function?

2.2.1 The electricity market design

An electricity market design has been conceptualised as a set of interconnected markets in which each individual market serves a specific purpose (Franco et al. 2015; Roques and Finon 2017; Pownall et al. 2021). The electricity market design within GB is comprised of the following six markets:

2.2.1.1 The wholesale market

The wholesale market facilitates the trade of electricity between BSC parties[1] (generators, suppliers, and non-physical traders[2]). As explained within section 2.2 trading within the wholesale market is facilitated via two mechanisms: bilateral trading and an exchange. The wholesale market facilitates the largest volume of electricity trading within GB in terms of energy and value (See Table 5).

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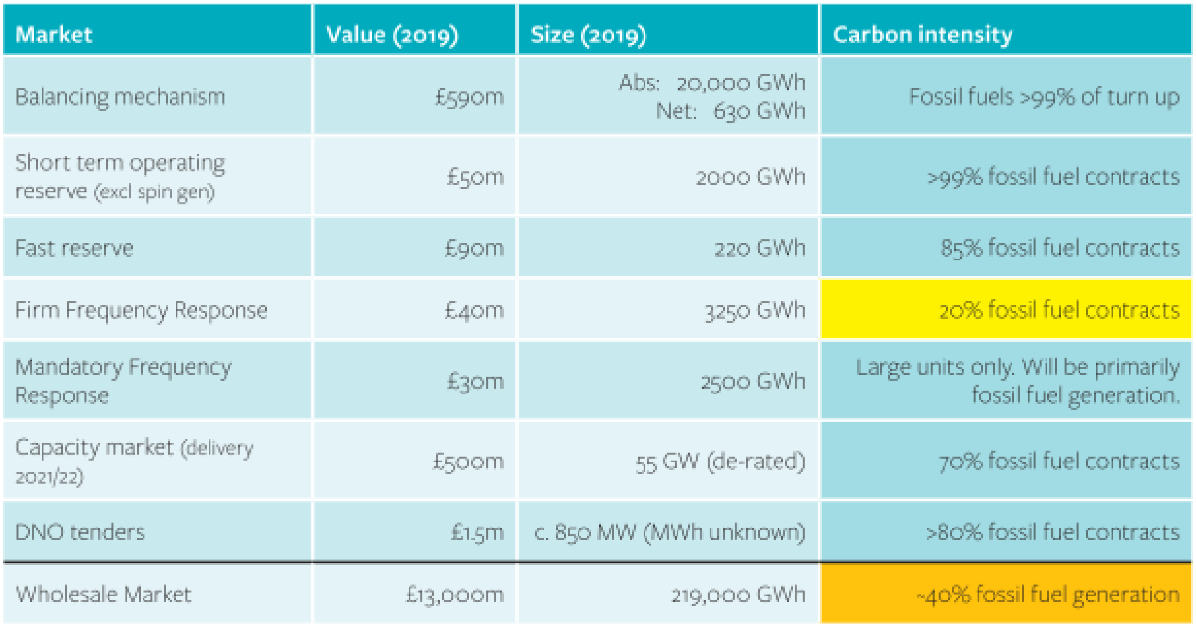
[1] Balancing and Settlement Code (BSC) parties are those which have acceded to the balancing and settlement code.

[2] Organisation without a physical demand for electricity, or means to generate electricity, such as banks (Elexon 2017a) which have a purely financial interest in trading.

Table 5 A comparison of several markets in terms of their value, size and carbon intensity. Sourced from (Sandys and Pownall 2020)*. Gigawatt-hours (GWh).*



Market	Value (2019)	Size (2019)	Carbon intensity
Balancing mechanism	£590m	Abs: 20,000 GWh Net: 630 GWh	Fossil fuels >99% of turn up
Short term operating reserve (excl spin gen)	£50m	2000 GWh	>99% fossil fuel contracts
Fast reserve	£90m	220 GWh	85% fossil fuel contracts
Firm Frequency Response	£40m	3250 GWh	20% fossil fuel contracts
Mandatory Frequency Response	£30m	2500 GWh	Large units only. Will be primarily fossil fuel generation.
Capacity market (delivery 2021/22)	£500m	55 GW (de-rated)	70% fossil fuel contracts
DNO tenders	£1.5m	c. 850 MW (MWh unknown)	>80% fossil fuel contracts
Wholesale Market	£13,000m	219,000 GWh	~40% fossil fuel generation

Trading in the wholesale market occurs across a timeframe spanning from decades in advance up to gate closure. Using these timeframes as indicated by the International Energy Agency (IEA) (2016), the following section will summarise what typically occurs during these different timescales. These represent one form of trading across different timescales including long-term, forward trading, and SPOT trading.

The long-term market: The investment market (3-25 years)

This long-term market is also referred to as the 'investment' market. Many new-build generation systems such as a solar or wind farms will be operational for 25 years or more (IEA 2016). Investors therefore make assumptions about the changes to demand, future capacity mix, fuel costs and other factors over this multi-decade timescale, all of which influence the price of electricity and thus their potential return on investment (RoI) (IEA 2016). Long term contracts for the off-take of electricity may be struck at this point, such as a power purchase agreement (PPA), CfD or capacity market contract which can range from ~10-35 years. These contracts may be between a utility and an independent power producer, or via a government-backed organisation such as the LCCC which is the counterparty for CfDs and the capacity market.

The Forward/Futures market (1-4 years)

Markets on this timescale, often referred to as forward trading markets, provide routes to hedge against a volatile market price by locking in prices and volumes of electricity in advance (Redl et al. 2009; ACER 2015; IEA 2016). Hedging is the act of market participants procuring, or selling, capacity ahead of gate closure to secure a proportion of their requirements and therefore reduce their exposure to the potentially volatile SPOT price (Redl et al. 2009; Botterud et al. 2010). This act is vital for both small and larger market participants, with the former facing a greater possibility of defaulting due to extreme movements in the SPOT market and smaller capital reserves to deal with such expenses (ACER 2015). This can be evidenced with the number of energy suppliers defaulting during the 2021 energy crisis which is being attributed to the increase in energy prices combined with suppliers who are not hedged against this price volatility (Cornwall Insight 2021a; Sky News 2021). This builds upon entrant risks discussed thus far, including dealing with complexities, unexpected costs and the exposure to higher levels of risk.

Hedging does not protect from all risk, as unforeseen circumstances such as a plant malfunction would place the generator at risk for anything that is not covered in their hedging strategy (CMA 2015a). Furthermore, if a product is traded multiple times (the churn rate) it provides price discovery of the underlying product which in turn can be used as a reference price for that product in future hedging strategies (ACER 2015).

There are many methods to hedge within the GB's current electricity market design, including the procuring of standardised products via bilateral contracts, which include financial products such as futures, options and forward (Deng and Oren 2006; Wimschulte 2010; Ofgem 2016a; Trayport 2019), as well as arrangements bespoke to the requirements of the counterparties (IEA 2016). The prices for electricity within these hedging contracts are primarily based upon the historic price in the SPOT market (Deng and Oren 2006; Redl et al. 2009). Therefore, whilst the majority of electricity is traded at this forward timescale, the SPOT market will influence the prices struck within these arrangements.

The operational decision phase (1 year – the SPOT market)

From a year ahead to the opening of the SPOT market, there are many operational decisions to be made. These are especially pertinent for VRE and storage units who are unable to rely on a firm source of fuel for their output.

For example, it is at this timescale where weather forecasts can provide the basis for commercial strategies for VRE technologies. There is however a risk associated with setting up bilateral trades based on these forecasts which may diverge from actual weather conditions on the day. This can lead to charges for not delivering on their contractual agreements, known as imbalance charges; the cost of the corrective actions required (Elexon 2017a).

This is a similar consideration for storage units who will base their commercial strategy on their opportunities to generate revenue based on performing different functions. Within the wholesale market this would be utilising arbitrage opportunities, whereas another option is to provide services via the balancing mechanism or ancillary service markets. These decisions will be made within this operational.

The SPOT market (The day head and intraday)

The SPOT market refers to the trading of electricity as a product in the 48 hours before gate closure. In reality this is split into two markets: the day ahead market (DAH) operating 48-24 hours ahead of gate closure, and the intraday market (ID) from 24 hours to gate closure. This timescale is the focus of the thesis. Trading at these timescales enables market participants to adjust their position. Any apparent surplus or deficit of electricity against their contracted position from the forward/futures market may be resolved through adjustments in these almost real time markets, therefore reducing the risk imbalance charges from the SO.

This timeframe for trade has been recognised to be of increased importance for VRE generating assets and flexibility service providers because operating close to real time permits more accurate generation and demand forecasting and allows actors to re-position themselves to mitigate imbalance charges (Lin and Magnago 2017; EPEX SPOT 2020). In this way, EPEXSPOT (2020) forecasts that trading closer to delivery will become increasingly important as further VRE is deployed; equally, the details of the trading arrangements in these short-term markets will impact the level of integration of these technologies and services (IEA 2016).

The short-term markets are therefore necessary, but prone to price volatility, leading to the majority of trade being conducted in the medium and long-term (KU Leuven Energy Institute 2015; IEA 2016). Appendix one exemplifies how the trade of electricity under the GB’s current market design set up occurs.

2.2.1.2 The balancing mechanism[1]

National Grid ESO has a statutory obligation to economically balance electricity supply and demand second by second, to ensure that the grid is maintained at its design frequency of 50Hz, deviating only by ±0.5Hz, in order to keep the lights on (National Grid ESO 2020d). This function of this mechanism requires operation close to real time and is therefore included within the timescales of the thesis. When a market participant deviates from their contracted position an action is required to ensure that generation is increased or decreased. National Grid ESO fulfils this role by accepting and rejecting bids and offers submitted, by those participating within the wholesale market. These bids and offers are submitted on a bilateral basis and therefore the prices paid for these actions are not transparent, however, the technologies which contribute these services are reported under the monthly balancing services summary (MBSS). The data shows that actions accepted by National Grid ESO to balance the network are dominated by instruction for utilise CCGT plants (Figure 5). Furthermore, according to BEIS's data in Table 5 all contractual agreements entered in 2019 to perform balancing actions, 99% of the accepted bids and offers were with fossil fuel generators (BEIS 2020c)**.**

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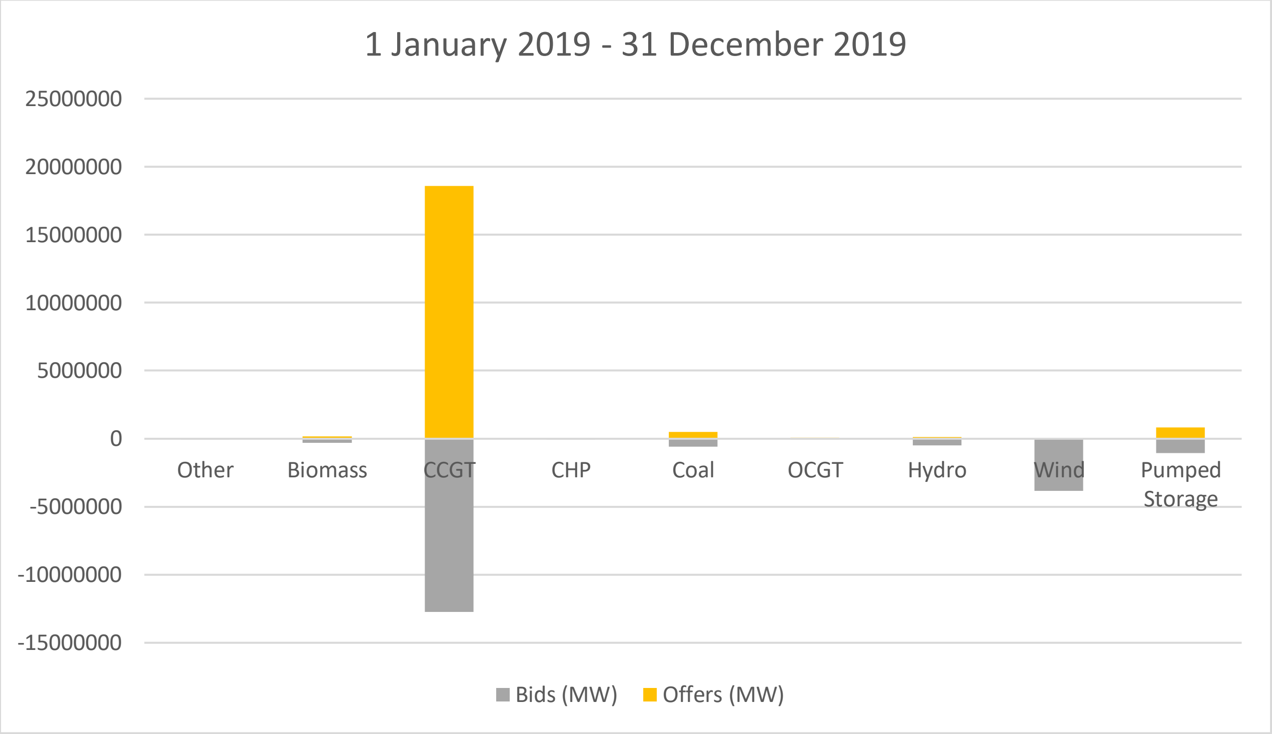
[1] Often referred to as the 'balancing market', 'real-time market' and 'regulatory market'.



1 January 2019 - 31 December 2019		
	Bids (MW)	**Offers (MW)**
Other	-496	9,550
Biomass	-298,881	172,085
CCGT	-12,717,659	18,585,828
CHP	-5,134	44,410
Coal	-577,662	516,976
OCGT	-4,714	81,816
Hydro	-496,627	142,853
Wind	-3,846,178	20,584
Pumped Storage	-1,064,720	846,617

Figure 5 The forms of technologies call upon within the balancing mechanism, highlighting the dominance of CCGT. Offers are indicated by orange (being paid to come online) and bids are in grey (being paid to turn off). Data Source: LCP email correspondence.

The majority of bids and offers are accepted at the start of the gate closure period. This is in part due to the characteristics of the CCGT thermal assets which are typically large plants with high minimum export limits (i.e. 400MW minimum production) and the need for adequate time to prepare for instructions from National Grid ESO i.e. warming up. With National Grid ESO taking actions earlier on, it means that only smaller actions are required from newer forms of technologies which as battery storage which operate closer to real time. This relationship is illustrated in Figure 6 below.

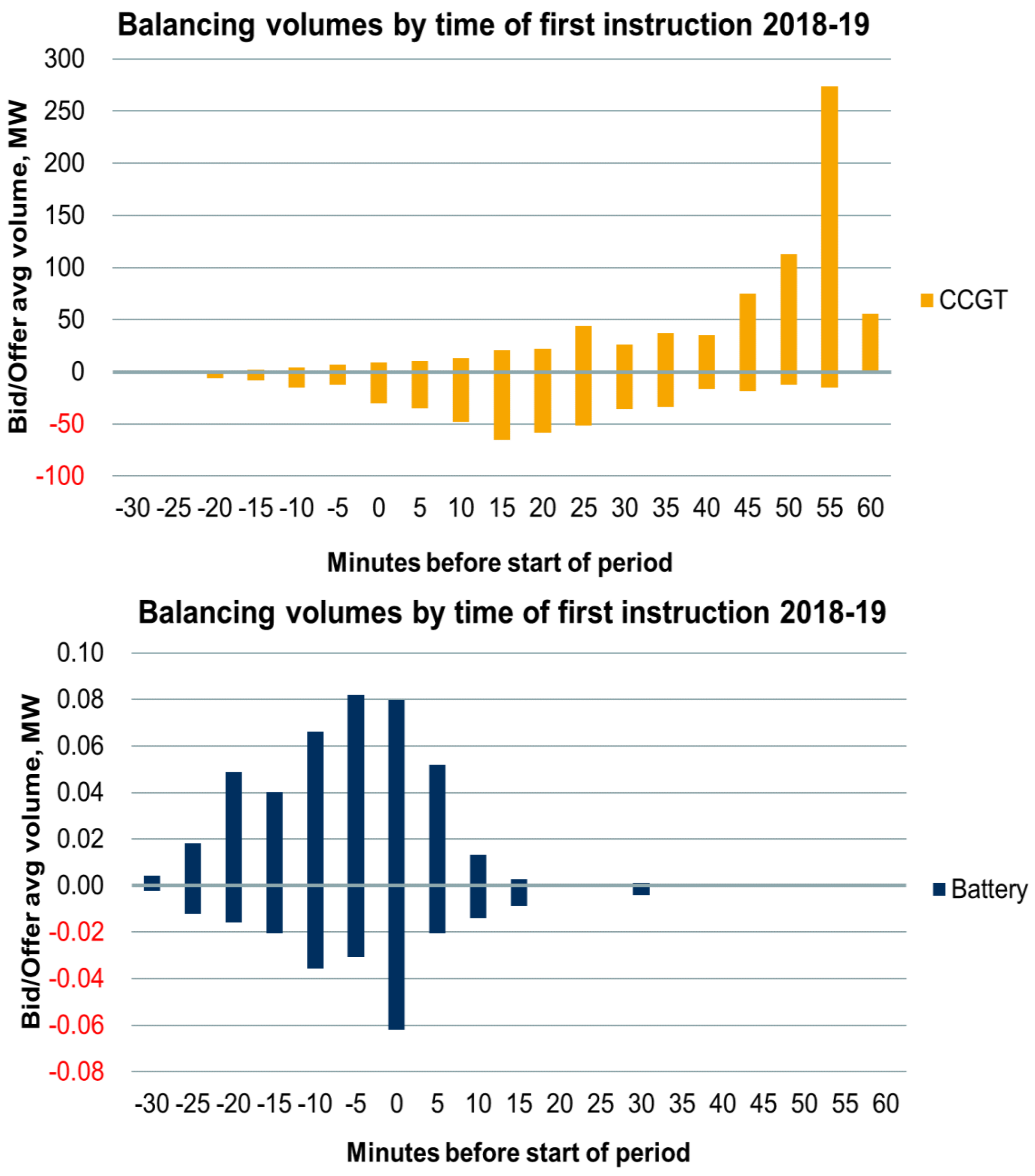


Figure 6 Balancing volumes by time of first instruction. Note the difference in scales on the 'bid/offer avg volume, MW' on the y-axis. Images sourced from emails with LCP energy analytics.

The current regime of instructing balancing actions from fossil fuelled plants at the beginning of the gate closure period is a continuation of the electricity market design rules present at the beginning of NETA. This allows for the majority of dispatch volumes to be met by fossil fuelled generation, rather than battery storage[1] or other non-fossil

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[1] Although the carbon intensity of the export from battery storage units is dependent upon what is extracted from the grid, under an increasingly VRE-dominated network battery output is likely to be progressively lower carbon compared to CCGT.

fuel forms of flexibility. This provides another example of the advantage that incumbents who have invested in firm fossil fuelled technologies have over their zero carbon counterparts.

2.2.1.3 The ancillary services market

In addition to the balancing mechanism, National Grid ESO procures a range of products via their ancillary market which are utilised following gate closure to ensure grid stability by mitigating frequency deviation events which could result in power loss, equipment damages and the disconnection of consumers (IEA 2016; Energy UK 2017). A list of these products and a description of them can be found within appendix two. The ancillary market includes products procured over timescales varying from months in advance, such as the enhanced reactive power service which is procured every six months, to daily tenders for products such as Dynamic Containment (DC) (National Grid ESO 2021a). The proximity of the ancillary service markets to real time and therefore influencing the operation of service providers is an important aspect of the electricity market design within the scope of this thesis.

There are signs that the services being procured within the ancillary market are changing. For instance, historically, the services procured were primarily from generators connected to the transmission network - but recently the technologies procured are more diverse as a result of the changing plant mix and increased participation of the demand side within the GB electricity system (Energy UK 2017). However, it remains the case that for many of the products procured the entry requirements - what is required of the provider - still align with the characteristics of the historical electricity mix, and therefore hinder market entry for newer technologies and services (Pownall et al. 2021).

National Grid ESO has recognised certain barriers to integrating a higher proportion of VRE technologies into the ancillary market, such as large clip sizes[1] and long-term contracts which hinder the ability for VRE and other units which operate on shorter timescales. National Grid ESO are developing many of these markets to reduce these barriers, the details of which are summarised in appendix two. Whilst these

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[1] This is the minimum threshold of power required to enter into a particular market or service.

changes will be welcomed by operators of VRE, hurdles remain. For example, the fast reserve market has seen a reduction in the aggregated clip size from 50MWs to 25MWs (National Grid 2018; National Grid ESO 2019a) which, whilst lower, is still a large amount of capacity for decentralised technologies (e.g. the vast majority of UK solar farms have a capacity below 25 MW (BEIS 2021d)) and thus still poses a barrier to many newer, smaller technologies and services.

For the majority of products, the access requirements for the ancillary market are unsuitable for many variable and small-scale service providers, hindering their access to potential revenue streams. This highlights how the economics of GB's electricity market design and the access to value are still skewed away from the technologies and service providers which will be required in a net zero power sector, which results in disadvantageous investment incentives.

Through the balancing mechanism and the ancillary market, National Grid ESO holds considerable agency in deciding what services are deemed necessary and should be valued - and they determine which technologies and service providers can provide these through setting out specific entry requirements[1]. Entry requirements can exclude new market participants from particular revenue streams which sends signals to investors about what technologies or services they should invest in.

National Grid ESO are directly responsible for the set-up of the ancillary market and the balancing mechanism, but there are signs that they have an influence over the wider wholesale markets as well. For example, their 2020 FES is a heavily cited piece of literature, often considered among the key documents forecasting the future electricity system and the role of the ESO (National Grid ESO 2020a). National Grid ESO are also collaborating with BEIS and Ofgem in research to develop future GB electricity market design concepts[2]. As such, they will be centrally involved in decisions which are likely to influence the nature and location of revenue streams and access to them.

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[1] The process for National Grid ESO to design and implement a new product is outlined within Chapter 3. In short, Ofgem must approve any products and the design of any product must be consulted with industry.

[2] The researcher has been in contact with a new team within National Grid ESO who are looking into the future arrangements of the electricity market design within GB. Their research is in the early phase and therefore there is not citable material at the time of writing.

2.2.1.4 The capacity market

In 2010, the UK government announced plans for the EMR to ensure that the market design would promote energy security citing concerns resulting from the increased deployment of VRE (DECC 2012a). The EMR introduced several amendments to GB's electricity market design including the introduction of a capacity market within GB. It was argued by DECC that such a mechanism was required as a means to stimulate efficient investment to ensure security of supply (Mitchell 2014a; Lockwood 2017; Bray et al. 2018). The introduction of this module evidences the inadequacy of the wholesale market in stimulating new investment.

The capacity market was designed to ensure sufficient 'reliable' capacity is available by providing payments either to encourage investment in new capacity, or for existing capacity to remain in operation. Generators can bid for contracts in different capacity market auctions:

- The T-4 auction: Held four years in advance of delivery and is where the majority of capacity is auctioned
- The T-1 auction: Held one year in advance of delivery used to 'fine-tune' the amount of capacity auctioned for
- The transitional arrangement (TA) auction: a single bespoke auction for DSR held in 2017[1]

The capacity market operates through a central purchaser, the LCCC, and is a market-wide approach intended to allow all forms of capacity to bid into the auction. Successful capacity receives a monthly 'capacity payment' on top of earnings from the provision of other services such as to the wholesale market.

Successful bids receive payment for available capacity on a pay-as-clear principle. It follows that the most expensive bid accepted sets the marginal price. Specific characteristics such as flexibility and carbon intensity are considered extraneous, therefore capacity provided by a CCGT is paid the same price as that from a hydroelectric generator despite their difference in carbon (Lockwood 2017).

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[1] Though one may consider a bespoke auction for DSR to be in line with net zero. In reality, the capacity allocation for this one-off auction with 1.5% capacity allocation compared to that of a typical T-4 auction.

New plants can receive contracts for up to 15 years whilst refurbished plants can be awarded contracts of up to three-years. Providers are expected to be available to respond with their agreed generation volumes or load reductions when called on by National Grid ESO at times of system stress.

At times of system stress, which is defined at capacity margins being less than 500MW for a given period, National Grid ESO will announce a capacity shortage by sending capacity payment recipients an 'Electricity Capacity Market Notice' to signal to recipients that they may be required to reduce the stress events. Though the capacity market offers long-term contracts, the units themselves are activated in the short term and therefore this market, and potential reforms to it, are in the scope of this thesis.

At the time of writing, the capacity market has provided capacity payments totalling over £4.7 billion, a cost estimated to be £14 per year per household[1] that will be recuperated from electricity bills (DECC 2012b; Lockwood 2017).

Despite the huge financial cost of the capacity market, there are concerns over whether this market has performed as intended. The capacity market has been a controversial mechanism in both its design and effect (Lockwood 2017). This mechanism has been seen to benefit existing, often high-carbon, technologies rather than introducing new capacity and new technologies such as demand side response (DSR) (IEA 2016; Lockwood 2017). Due to the dominance of existing plants among successful bids at the time of its introduction in 2014, this new mechanism is yet to deliver an adequate pricing signal for to deploy new capacity, but is instead supporting old thermal assets (Figure 7) (Lockwood 2017; Cornwall Insight 2020a).

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[1] However, it should be noted that DECC in conducting this modelling acknowledge multiple factors which can impact this price, i.e. the amount of capacity procured, and the clearing price and this price should be considered a rough estimate.

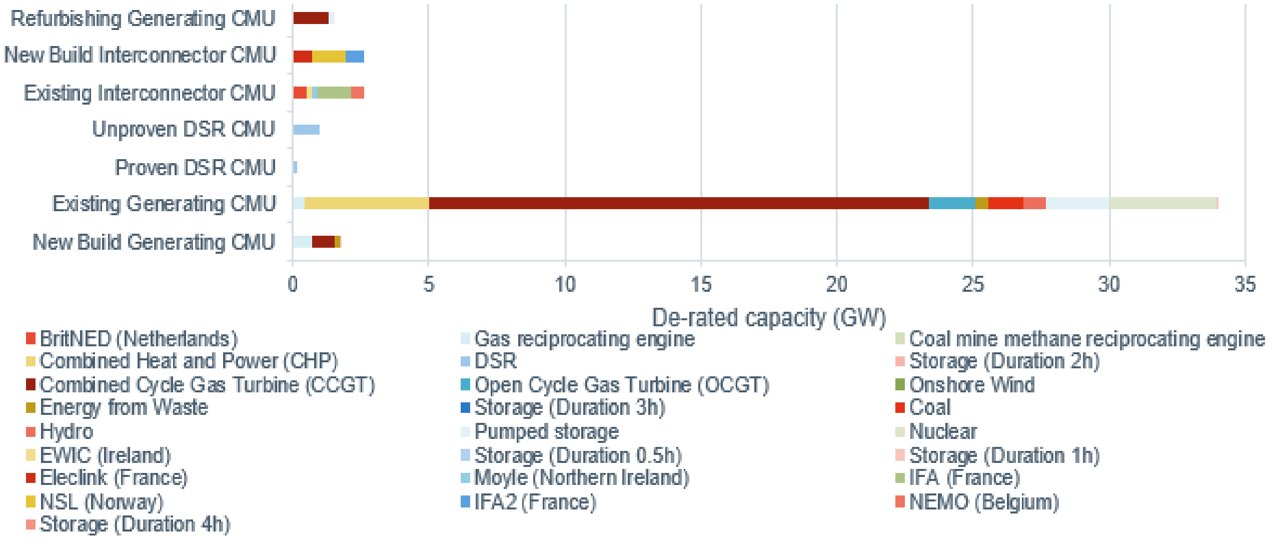

Figure 7 A breakdown of capacity awarded T-4 agreements in the 2020 capacity market auction. It is clear that the majority of capacity market contracts are awarded to existing capacity market units (CMU) of which the majority of these are CCGT. Source: (Cornwall Insight 2020d).

2.2.1.5 Local electricity markets

Locally-owned private electricity trading platforms are emerging within GB which include the flexibility markets operated by the Distribution Network Operator (DNO) (via Piclo Flex) and LEM's operated by third parties such as Centrica (Bray et al. 2018). This demonstrates that new modes of operation for the buying and selling of electricity are possible.

Within GB, a governance transition within the DNO is occurring towards a 'Distribution Systems Operator' (DSO) style organisation (ENA 2017). One of the additional functions of these new institutions is tendering for flexible technologies and services to relieve constraints on the network which are becoming increasingly commonplace as more decentralised technologies are being deployed (Ofgem 2017a). Between January to June 2021, a new record of 1.6 Gigawatts (GW) of flexibility has been contracted across the GB's distribution network freeing up the network – a capacity cited as being the equivalent of connecting 32,000 rapid Electric Vehicle (EV) chargers (50kW) (ENA 2021a).

These marketplaces demonstrate new and innovative means for procuring services required, such as flexibility, from decentralised technologies via competitive means. However, there are concerns that these local private platforms are extracting value from flexibility without contributing towards the cost of the infrastructure. These costs are instead being covered by 'Distribution Use of Service' (DUoS) and other network payments (i.e. costs passed on to the end consumers). Therefore, if the cost incurred through third parties via the procurement of network services increases, then so too will network charging via DUoS (Willis et al. 2019a).

These marketplaces remain small relative to the others introduced within section 2.2 thus far and, similar to the other marketplaces identified in Table 5, the majority of contracts agreed in local markets are with fossil fuel generators. Referring to Table 5, 80% of DNO tenders were awarded to fossil fuelled generators during 2019, as illustrated in Figure 8 below.

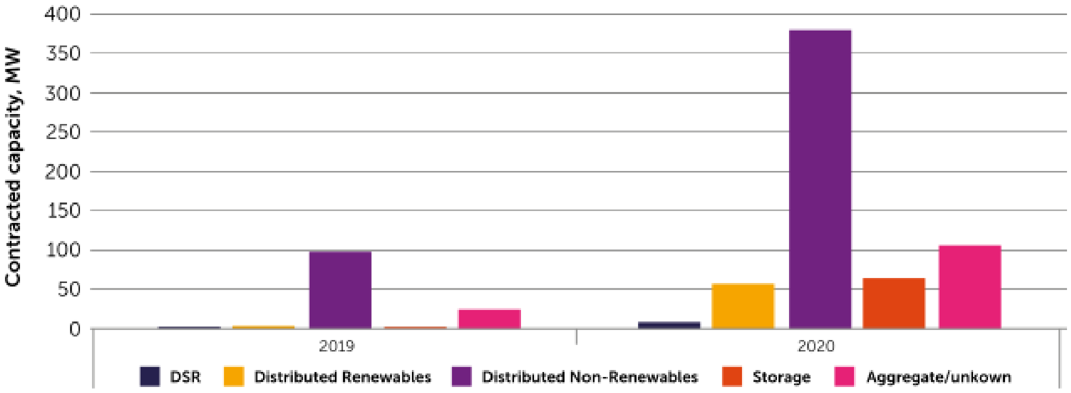

Figure 8 *Traditional generation making up the majority of DSO service contracts to date. Source:* (National Grid ESO 2021c).

2.2.1.6 Low carbon subsides

Within GB a range of subsidies have been developed and implemented since the 1990s to incentivise the deployment of non-fossil fuel technologies. Whilst these are not 'markets' in themselves, these subsidies are primarily paid based on generation output. Therefore, recipients are incentivised to generate regardless of system conditions which has repercussions for the wider system and marketplace. This section introduces these subsidies, and chapter five explores the impact of these subsidies on the other marketplaces.

Subsidies for renewable generators within GB's electricity market design were initiated in 1990 with the non-fossil fuel obligation (NFFO) which regulated Regional Electricity Companies (RECs), the predecessor to the DNO, to secure a specified amount of new generating capacity from non-fossil sources (Mitchell 2000). 2002 saw the introduction of the Renewables Obligation, superseding the NNFO, requiring that UK electricity suppliers source an increasing proportion of their electricity from renewable generation. Renewable generators are issued Renewable Obligation Certificates (ROCs) which are purchased by the electricity suppliers. The Feed-in Tariff (FiT) was introduced in 2010, designed to promote the uptake of small-scale renewable and low carbon technologies. Payments vary between the generation technologies installed and depend on the energy generated and the amount exported to the network. In this way, small scale VRE is settled by the retail market with their value being centrally determined by Ofgem, and not the free market as is the case for their larger counterparties.

All of these means of subsidising non-fossil fuel generation have now been closed to new entrants though existing contracts are still being honoured until their specified end date. Therefore, their legacy will continue to impact the operation and efficacy of GB's electricity market design.

2.2.1.7 Long-term investment contracts

The government has introduced a range of long-term contracts which were introduced to underpin investment into new assets; many of which are discussed within Section nine within Appendix six. For example, the CfD was introduced via the EMR, and legislated in the Energy Act 2013 (CMA 2016a). This was a government scheme by which low carbon generators receive payments for their generation in line with the wholesale price of electricity.

- As set out within the previous chapter, such long-term investment contracts were outside the scope of this thesis. Nonetheless, their impact upon the efficacy of GB's electricity market design, as will be explored within Chapter five section 5.1.2, warrants further research into their design.

2.2.2 The interconnected nature of these markets

While each market has a particular focus, they do not operate in isolation. Rather, actions taken within one market have knock-on impacts on others. For example:

1. As explained in section 2.2.1.4, during times of system stress, when there is less than 500MW of spare capacity, National Grid ESO will signal a system warning to

all those in receipt of a capacity payment that they may be required (National Grid ESO 2021b). This system warning provides a signal that extra capacity is required, highlighting to those with spare capacity to sell into the wholesale market or balancing mechanism (Cornwall Insight 2021b).

2. Seven battery units are active within the balancing mechanism as of January 2021, an increase on the previous year. This trend in deployment is likely to continue as more units are constructed under contracts issued in the capacity market (Cornwall Insight 2021c).

2.2.3 Routes to market

There are various means for operators to realise the value from electricity generating assets within the current electricity markets as illustrated by Figure 9.

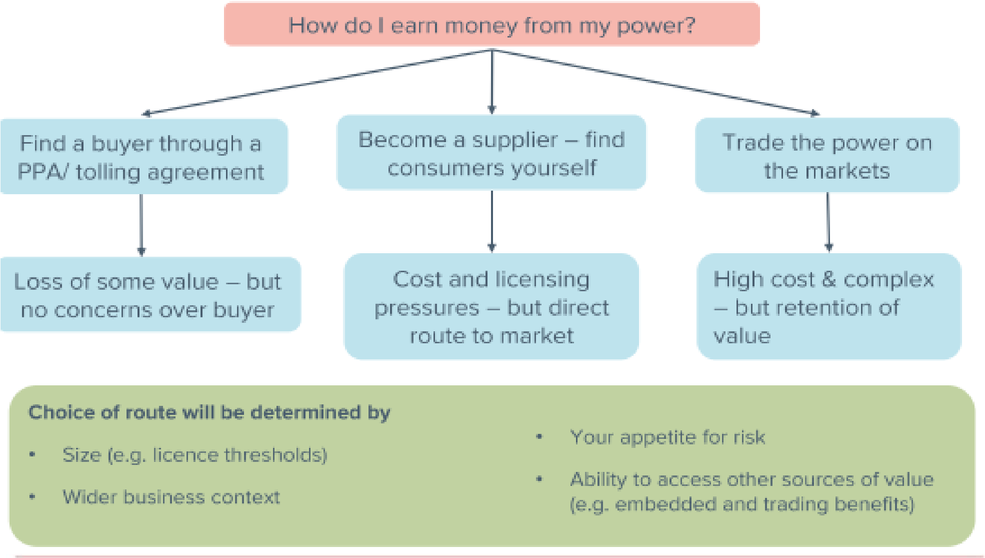

Figure 9 A tree diagram representing the various routes to earning value from energy. Source: (Cornwall Insight 2018a).

2.2.3.1 Become a supplier

Obtaining a supplier licence provides a direct route into the wholesale market. This route requires a high level of investment for set-up as well as compliance with multiple regulatory and code bodies requiring time, knowledge and expertise. Financial costs include the lodging of credit, the subscription fees to each individual code body, operating a 24/7 trading team and dealing with the considerable risk of dealing with a volatile electricity price and imbalance charges (ACER 2015; Ofgem 2016b; Elexon 2021).

As such, this route is not suited to all those wishing to enter into the wholesale market and other means such as the PPA or direct trading may be more appropriate or accessible.

For small generators there are two routes into the wholesale market: Central Volume Allocation (CVA) and Supplier Volume Allocation (SVA) (Elexon 2017a). These operate as follows:

- CVA: an agreement which permits a generator to access the wholesale market **directly** – typically for those connected to the transmission network.
- SVA: an agreement between generator and willing licensed supplier, via a PPA, i.e. **indirectly** – typically for those connected to the distribution network

In order to qualify for the CVA route, under the BSC requirements there are a number of steps to undertake, including CVA testing, credit contacts and a £250 monthly BSC membership fee.

Direct access to the wholesale market introduces additional pricing risk through the cost of imbalance which can materialise if a generator does not fulfil their contracted position. During the period between the 6th-8th of January 2021, the 'Beast from the East 2' brought cold weather, low wind and solar output leading to tight margins on the system with imbalance prices hitting highs of £4,000/MWh (Elexon 2021a). This could be disastrous for a small generator without the financial buffer of large incumbent generators. They are also unlikely to have the funding to equip the trading team required to operate effectively within the wholesale market (Bray et al. 2018). Therefore, the risks and requirements of operating within the GB electricity market under a CVA license are heavily weighted against those without the financial backing of an incumbent generator, providing another form of incumbent advantage.

The alternative is an SVA, which is typically utilised by generators connected to the distribution network and requires partnering with a licenced BSC supplier to registers the asset on the generator's behalf. In this case, the supplier would either register the generators as a standalone BMU[1], for £100 a month, or register the asset

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[1] A balance mechanism unit, (BMU), is the smallest unit of trade within the balancing mechanism to which energy production or consumption is accredited. It is these BMUs which a BSC party will use to participate in the balancing mechanism (Cornwall Insight 2018e).

under their existing BMUs where it would count as negative demand (Bray et al. 2018). This route restricts the generator to selling their power to that licensed supplier, likely via a PPA. So, whilst this route reduces risk for smaller generators with DER it limits trading opportunities - generators may not trade with local buyers or directly in the wholesale market as incumbent counterparts can. This unfair advantage favouring large incumbent generators is a legacy of the trading arrangements introduced with NETA and is a policy that current developments are seeking to reverse by enabling embedded generation[1] to trade with local demand. The Local Electricity Bill is a draft bill submitted to parliament which, if passed, would amend clauses within the Electricity Act 1989 and allow community energy projects to sell locally generated energy to local people; at the time of writing this bill is still in its early stages and therefore the details of such arrangements are unknown (Power for People 2020).

2.2.3.2 Power purchase agreements

A PPA is suited to those generators who do not wish to manage their own position, such as an embedded generator (one connected to the distribution network or located behind the meter) which does not have the expertise, resources or (under current regulation) have a direct route to market which a PPA counterparty can provide. In this example, the embedded generator contracts with a licensed BSC party who manages imbalance and trade on their behalf, with the terms detailed within the PPA in return for a share of the revenue from the energy sold. The BSC licence holder also gains a means to hedge against any possible deviations by utilising the output from another generator (Cornwall Insight 2018a).

Analysis by Cornwall Insight highlights that PPAs for renewable and flexible technologies are becoming an increasingly sought-after route to market[2], and in 2018 an estimated 65% of VRE was under some form of PPA (Figure 10) (Cornwall Insight 2018b, 2020b). Contracts are either established through direct negotiation or facilitated by a third party such as NFPA's e-power monthly auctions for 6 month PPAs (NFPA 2021). On this basis and in response to a consultation conducted by REGEN (2019) many energy

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[1] Those located on the distribution network.

[2] Estimated 65% of VRE is estimated to be under some form of PPA (Cornwall Insight 2018b)

suppliers stated that they were not incentivised or had no plans to offer PPAs to generators lower than 30kW in output suggesting that this route to market may be inaccessible to very small generators and service providers.

Though PPAs offer a suitable route to market for smaller market participants the current institutional set up requires a third party to process revenues for generation or services who also receives a share. The complexity, resource-intensive structure and the lack of direct routes to market for smaller market participants presents a clear challenge for the current trading arrangements which must be addressed.

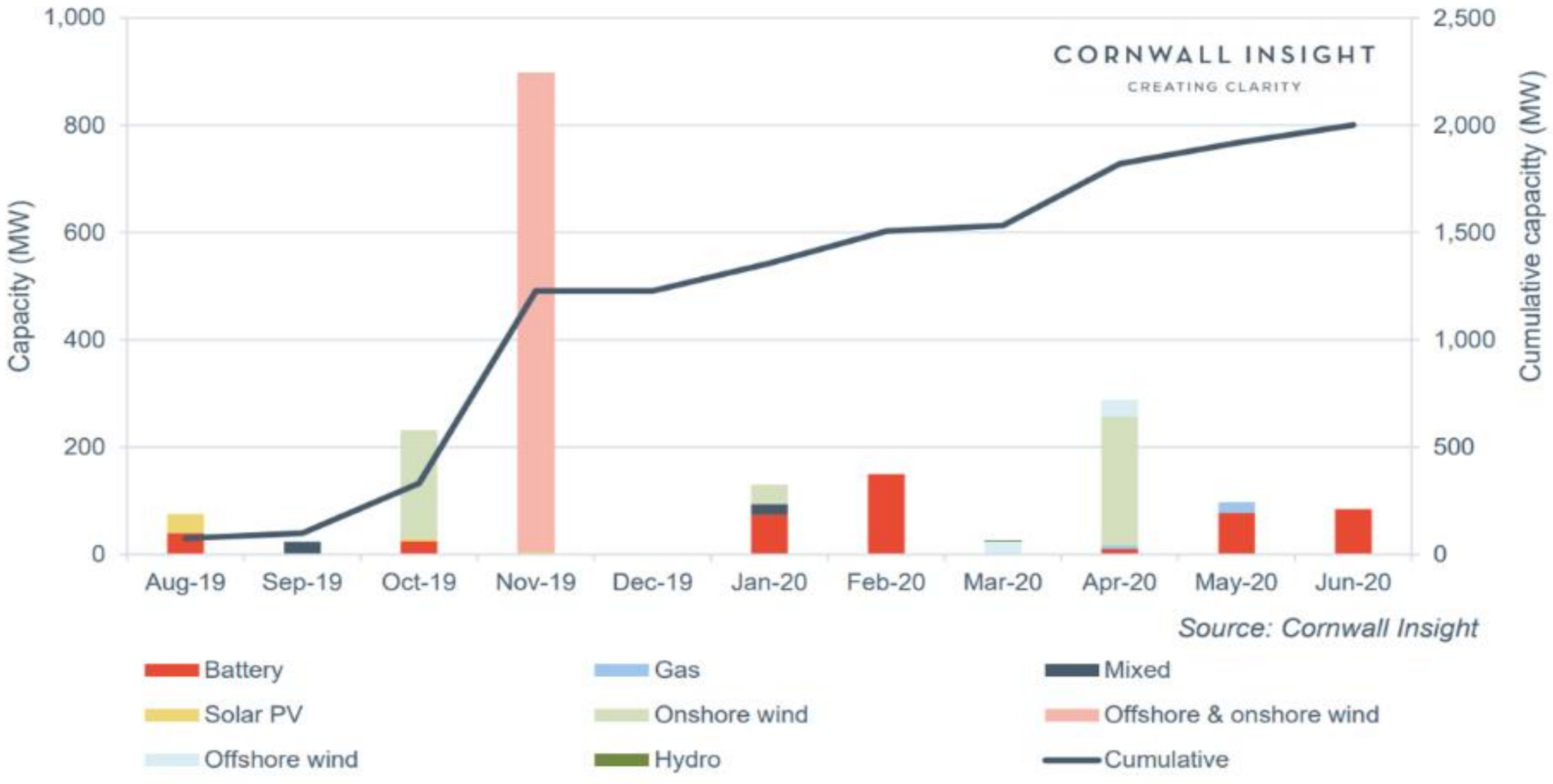

Figure 10 Capacity of new flexible and renewable PPA deals between August 2019 – June 2020. Source: (Cornwall Insight 2020b).

2.3 The efficacy of GB’s current electricity market design in relation to these objectives

Reviewing the objectives of the electricity market design provides a methodological basis on which to judge the extent to which GB’s current market design is fit for purpose and to justify an electricity market re-design.

A review of literature from the energy regulator at the time of privatisation, academics and a consultancy reveals three objectives for the electricity market design (OFFER 1998; Newbery 2005; Robinson 2019; Cornwall Insight 2020a; Gencer et al. 2020; HM Government 2020a):

- Efficient dispatch: Is the lowest cost resource being activated to meet demand?
- Adequate capacity: Is there enough capacity to meet demand?
- Optimal investment: Is the lowest possible cost resource built to meet demand?

More recently, and therefore distinct from the three original objectives above, the need to achieve the legislated target of net zero carbon emissions from the power sector by 2035, which has become an additional requirement of the electricity system (Cornwall Insight 2020a; BEIS 2021a). This thesis will also consider a fourth objective of GB’s electricity market design:

- Do the rules of this institution aid in the facilitation of net zero in the context of decarbonising the electricity sector within GB?

The importance of these objectives stem from how essential the secure supply of electricity is to the economies of GB and indeed most of those across the globe. In pursuing these objectives there should be the security of supply today and in the future whilst aligning to the aforementioned 2035 net zero target.

2.3.1 Efficient dispatch

The efficiency of dispatching generation can be monitored by comparing the short-run marginal cost (SRMC) of generating an additional unit of electricity (Cornwall Insight 2020a). In other words, does the system successfully dispatch the cheapest sources of generation first?

Figure 11 depicts the day-ahead power price along with the cost of CCGT and coal generation, showing that the price of electricity tracks the cost of CCGT production relatively closely

– the most efficient form of thermal capacity. In this case, an efficient dispatch would see CCGT setting the marginal price[1] displacing more expensive forms of generation such as coal. Figure 11 shows both the SRMC of coal and gas are mostly beneath the day ahead power pricing before 2019, indicating that both of these generating technologies have been dispatched. The blue rectangle highlights a period in 2019 and 2020 when the price falls below the SRMC of coal generation reflecting the cheaper cost of gas and the displacement of coal generation. This demonstrates that the least cost technology is being dispatched to meet demand, and therefore there are those that argue that the wholesale market can be considered efficient in dispatching capacity (Cornwall Insight 2020a). However, this assumption does not hold true when there are constraints on the network and the output from the cheapest generation is unable to meet its intended destination. This relationship and how this incurs an additional costs to the end consumer is explored in Section 5.1.3.

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[1] VRE generation such as solar and wind are unlikely to set the price of power in an exchange as these are settled on the pay-as-clear principle and therefore if a CCGT plant is required to meet demand their SRMC will set the clearing pricing as the more expensive form of generation based on SRMC.

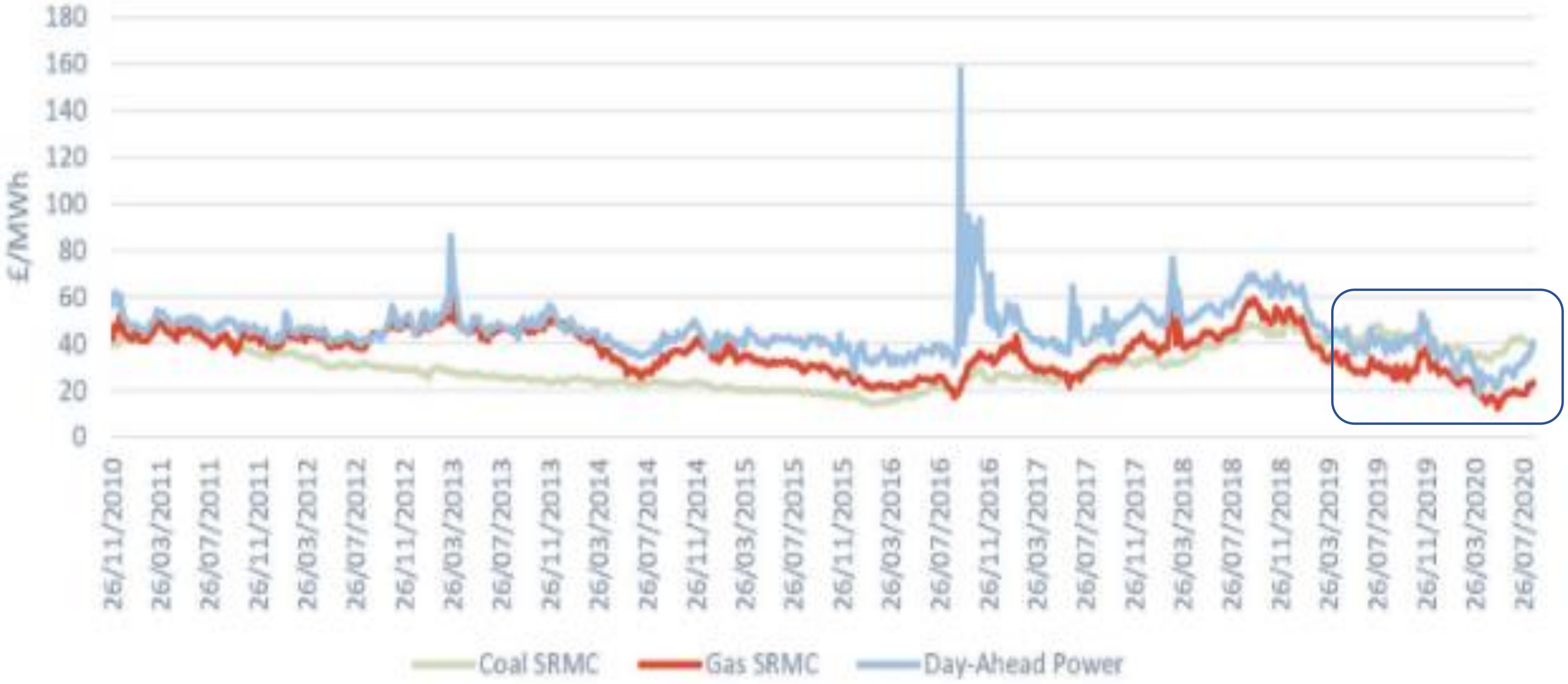

Figure 11 The day ahead power prices compared to the SRMC of both coal and gas. The close alignment highlights how the cost of coal and gas highly influence the day ahead market price. Source: (Cornwall Insight 2020a).

2.3.2 Securing optimal Investment and adequate capacity

The current wholesale market does not trade out far enough into the distance in order to hedge one's position, typically trading out no more than two to three years ahead of dispatch (Ofgem 2016c; Cornwall Insight 2020a). This is an insufficient timescale considering that newly built generators can operate for 30 years (Ofgem 2016c; Cornwall Insight 2020a). This indicates that generators have difficulty in building an investment case to secure the necessary finance to build a new asset based upon the wholesale market, thus leading to the implementation of a capacity market within GB (Cornwall Insight 2020a).

Given the scope of the thesis as outlined in section 1.8 which details the short termed focused of this thesis, the inability to trade out more than a few years, whilst a concern, is not an issue to be addressed within this thesis. For this thesis, the focus is on the design of these closer to real-time markets, and the investment signals that they send. As described in section 2.2.1.1, and throughout this thesis, these real time pricing signals provide the basis for future hedging and operational decisions. Therefore, rather than 'facilitating' investment, this thesis intends to focus on how the proposed electricity market design can deliver investment signals. These signals shall promote suitable locations on the network for deployment of service providers and the most optimal service provider given the locational characteristics of the network. Additionally, these signals intend to bring forward operations which enable the grid to be operated at least cost and carbon.

One may question how new plants were financed in the past if the wholesale market was not providing the investment signal. This is largely a result of a principally vertically integrated market structure. Vertical Integration (VI) provided a means to secure a route to market through an off taker for generation produced in-house, and this minimised the risks of operating within the market. In turn this improved a VI firm's credit rating reducing the cost of the capital required to finance these new generating assets (Steggals et al. 2011; CMA 2016b; Simshauser 2020). The Competition and Market Authority (CMA)'s Energy Market Investigation (2015b) acknowledged that in-house trading implemented via VI may have been an attractive proposition at the time of NETA's introduction due to the avoidance of imbalance costs. However, they argue that factors leading to this benefit from trading in-house do not apply under current market conditions, citing reasons such as high liquidity levels within the exchange based platforms allowing contracts with third parties to be struck, mitigating the risk of imbalance charges (CMA 2015b).

Furthermore, access to cheap finance is not supported under the current wholesale market, with the most promising signals for investors stemming from revenue assurance schemes such as the CfD and the capacity market. The majority of financing for a new asset is covered by raising debt against the project (i.e. against future generation), sourced from banks, pension funds, and venture capitalists (Cornwall Insight 2020c). Lenders have different risk appetites and expected RoI but ultimately require confidence in the prospect of a return in order to provide credit. Short-term trading on the wholesale market alone is generally insufficient to inspire investor confidence as price volatility is considered to create unacceptable risk from unreliable revenue (KU Leuven Energy Institute 2015; IEA 2016).

In addition, the efficacy of the wholesale market in delivering these investment signals is likely to worsen with the increased penetration of zero-marginal cost generators (Cornwall Insight 2020a). With groups of similar VRE technologies activated under the same environmental conditions, events such as high winds will result in many wind farms competing with each other. The high levels of generation with zero marginal costs, relative to a low levels of demand can lead to these generators competing and lowering their prices to be seen as competitive, leading to the suppression of the price received by these plants[1]. As such, the wholesale market is likely to clear at lower prices than can be used to secure long-term investment (Cornwall Insight 2020a). This process is illustrated in Figure 12.

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[1] This phenomenon known as price cannibalisation is further explored in chapter five.

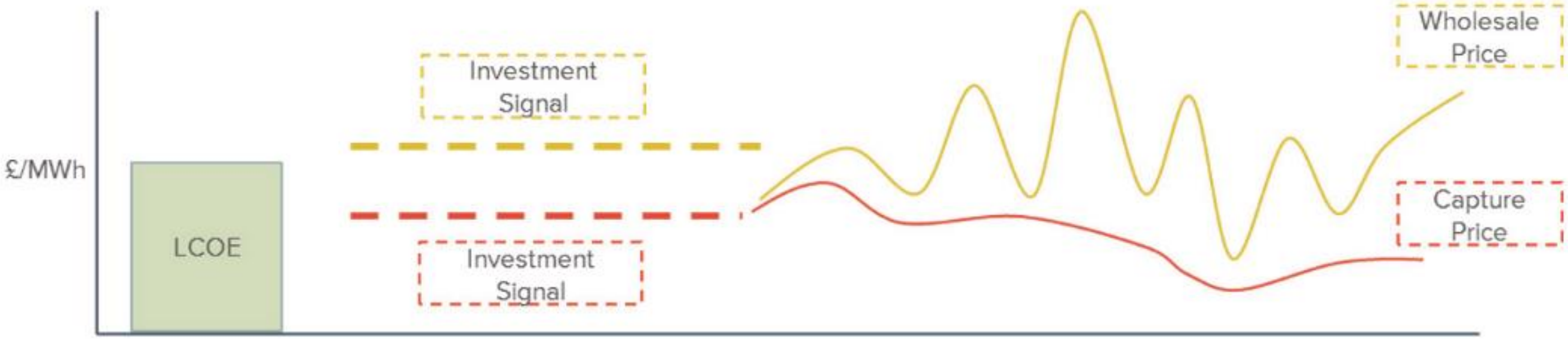

Figure 12 An illustration of the investment signals from the wholesale price and the actual capture price. Whilst the wholesale price reflects scarcity and excess, this is not always the capture price i.e. the amount that a resource provider would actually bank. For example, the high winds required for an offshore windfarm to generate will inevitable be powering adjacent turbines and therefore there is not the scarcity pricing as output is increased. This is reflected in a lower capture price. Source: (Cornwall Insight 2020a).

2.3.3 Net zero - the fourth and underpinning objective

Contributing to the achievement of net zero from the electricity sector has been argued by Cornwall Insight (2020a) to constitute a fourth objective of the electricity system and one which underpins the facilitation of the other three. For example, the efficient dispatch of generation must align with net zero – all technologies and resources to meet, or shift, demand must be from zero carbon sources.

As shown by Table 5 on page 55, the majority of markets are serviced by fossil fuel generating units. This provides evidence that under current market arrangements the fourth objective is not being met, delivering further justification for exploring alternative electricity market design arrangements.

2.4 Chapter conclusions

This chapter summarises how electricity is traded within the GB, and how these trading arrangements have been introduced and have evolved since the privatisation of the electricity sector in the late 1980's.

The objectives of GB's electricity market design have been identified from cited literature with a summary of how the current institution meets these four objectives. This provides an initial review into whether the current electricity market design is fit for purpose: whilst the first objective of efficient dispatch appears to be met, the current design is less successful in facilitating long-term investment, ensuring capacity availability or driving progress towards net zero emissions from the electricity sector. This provides the foundations for the argument that the current GB electricity market design is not fit for purpose and justifies the exploration of alternative arrangements. This argument will be built upon in chapter five which details the many issues reported in the academic, governmental and industrial literature and found within original empirical interview data to further justify the need for an electricity market re-design within GB.

The following chapter reviews the potential theoretical frameworks which can offer insights into the process of electricity market re-design. In doing so, this reveals a gap within the established literature for a readily available framework to explore this phenomenon. In light of this, chapter three proposes and justifies an appropriate theoretical framework to explore the process of electricity market re-design.

3.0 Theoretical perspectives on electricity market re-design

This chapter introduces the theoretical framework adopted to explore the third research question - What recommendations to policymakers can be identified to aid the process of contemporary electricity market re-design? Within this thesis, a theoretical framework is defined as a “structure that guides research by relying on a formal theory…constructed by using an established, coherent, explanation of certain phenomena and relationships” (Eisenhart 1991: 205; Grant and Osanloo 2014).

To the researcher’s knowledge, there has been to date a limited amount of application of theoretical perspectives to the process of electricity market re-design. Incorporating a theoretical framework connects research to an existing body of knowledge, providing a conceptual basis for the understanding of a phenomenon while guiding the researcher’s methodological approach (Sacred Heart University 2006; Grant and Osanloo 2014). The use of a theoretical lens has been argued to provide the tools to assess the implications a particular social structure, such as an electricity market design, whilst also improving the data analysis and interpretation of results through the identification of themes to explore (Sacred Heart University 2006; Fligstein and Dauter 2007; Grant and Osanloo 2014; Stewart and Klein 2016).

Applying a theoretical framework can provide insights to different audiences. Academics may find value from the identification of a means to conceptualise the process of electricity market re-design and contribute to the theorisation of institutional change. Policymakers may find value from having several tools to critique the process of market re-design, create generalisations and allow for a more in-depth understanding of the process of re-design which can aid in getting to a desired end point.

Therefore, this chapter will explore and identify a suitable theoretical framework to guide and critique the process of electricity market re-design. In particular, the tenets of both historical institutionalism and discursive institutionalism have been used extensively to analyse how institutions evolve and can be productively applied to the process of electricity market re-design.

This chapter proceeds as follows, the first section details how electricity market re-design occurs within GB -providing the subject for analysis. The second section starts with a brief review of possible theoretical frameworks, before introducing neo-institutional theory and exploring the four main strands. This is then followed by an exploration of institutional change as theorised within the strands of historical and discursive Institutionalism by building upon examples of how electricity market re-design occurs to justify this selection. The final section concludes.

3.1 Market re-design: how does electricity market re-design occur within Great Britain?

This section compiles the various conventional routes by which electricity market re-design can occur within GB. These include code modifications, those led by Government, Ofgem, National Grid ESO, the energy exchanges and the EU[1]. The purpose of this is to set out the processes which will be the subject of the theoretical analysis using the framework described in section 3.2.

The rules underpinning the electricity market design within GB evolve in a continuous process in which stakeholders play an important role; yet, the influence of market participants differs, with those with more resources (such as time, expertise and financial capital) dominating the discussion on both defining the problem and determining potential remedies (Correljé and De Vries 2008; Lockwood et al. 2019b).

GB's electricity market design has to a limited degree co-evolved alongside the wider characteristics of the electricity sector through the established means which will be discussed within this section. Yet, as will be shown throughout this chapter, change to the electricity market design is a slow and fragmented process dominated by those with the resources whose interests are to largely remain with the status quo which their business case is dependent upon. As such, there is evidence that this institution has not evolved to the degree required to reflect the characteristics of the wider electricity sector. A gap is expected to occur, as innovations as they emerge cannot be simply embedded into the electricity market design which follows a slow process of institutional change as will be introduced in the following sub-sections.

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[1] Though their agency to enact domestic electricity market re-design within GB has diminished as a result of Brexit.

Yet, a failure to sufficiently co-evolve the electricity market design with the characteristics of the wider electricity system can lead to critical issues for the broader economy, including high levels of fossil fuel emissions being produced, continued reliance on international imports rather than using domestic sources of VRE and the risk of blackouts as future investment signal are weakened as they are no longer reflected by this institution (Cramton 2017; De Vries and Verzijlbergh 2018; Gencer et al. 2020). The latter would result in fundamental disruption to the GB economy and would have significant ramifications to political leaders resulting from this disturbance to their constituents (Lockwood et al. 2019b). However, co-evolution will not occur without the expending of resources by engaged stakeholders ranging from market participants to governmental bodies. This section explores how the process of electricity market re-design within GB favours those that can expend resources, such as time, expertise and finance, providing an unfair influence on the process of this institutions' evolution.

There are a range of organisations which facilitate different roles within the process of electricity market re-design in GB. Table 6 summarises these roles.

Table 6 Organisations and their roles within implementing electricity market re-design.

Actor	Role within electricity market re-design
Agency for The Cooperation of Energy Regulators (ACER)	An independent body formed under the EU's third energy package legislation. This organisation's overall aim is to facilitate a transition of the European energy system to adhere with political objectives. Within this role they support the integration of new products traded on the nominated energy market operators (NEMO) markets, such as Nordpool and EPEXSPOT in GB (ACER 2020).
BEIS	Sets policies for the energy sector within the UK. Guidance on how BEIS goes about appraising policies, programmes and projects are detailed within HM Green Book (HM Treasury 2020).
Code bodies	There are several code bodies within the GB electricity system which oversee the proposal and implementation of modifications. More details on these organisations are provided in section 3.1.1 below.

DNOs	Limited to date, yet recent moves to design and develop marketplaces to procure additional network services such as flexibility. Designed in conjunction with the ENA and Ofgem. See, for example the flexible power program in which DNOs can directly procure flexibility services from those within their geographical regions (Flexible Power 2021).
European Commission	Sets out the guidelines for electricity market design of members states through packages such as the Clean Energy Package (CEP). Negotiations between the UK and the EU are still ongoing in regard to the relationship of these two, however the influence of this actor has been diminished as a result of Brexit. That said, the rules brought forward by the European commission will likely influence those within GB with the continued interconnectedness of these two regions.
National Grid ESO (ISO)	Design and development of new marketplaces for services procured within the balancing mechanism and the ancillary market. At the time of writing, Ofgem has consulted on the future roles and function of National Grid ESO in the context of facilitating the UK's net zero power sector target (Ofgem 2021b). Ofgem has assessed a range of potential setups for National Grid ESO which are detailed in Table 7 below. Of these, Ofgem is recommending that National Grid ESO is made fully independent from the transmission network owner, creating a new independent energy system operator (ISO). Combining the electricity and gas function into the ISO is welcomed as it contributes to a holistic energy sector. The consultation is closed, and awaiting a decision. As such, National Grid ESO will be referred to within this thesis, but there is the acknowledgement that this may be National Grid 'ISO' after the time of submission.

Ofgem	An arms-length body of BEIS. Decides on changes to the market rules to meet government policy.
Parliament	Parliamentary approval may be required within the process of electricity market re-design depending on the proposed scale of change, i.e. if it requires amending previous legislation. For example, the EMR required alterations to the legal text of the Energy Act 1989 and thus was needed to receive parliamentary approval.
Third parties i.e. Piclo	Development of new marketplaces for services such as flexibility which can be procured by DNOs.
Treasury	Sets out the guidelines for BEIS, and other governmental departments, for undertaking scenario analysis to determine policy direction (HM Treasury 2020). Her Majesty's Treasury also provides funding for such programmes.

Table 7 The four assessed options for the evolution of National Grid ESO. Ofgem commissioned FTI consulting to review these options against a criteria including efficiency, simplicity and ease of implementation. Source: (Ofgem 2021b).

Option	**Key characteristics**	
Description	**Degree of additional separation of unbundling**	**Fuel/vector**
Status quo: represents current system operator arrangements.	**None.** Reflects the current legal separation arrangements for the ESO and the fully integrated nature of National Grid Gas Transmission (NGGT).	Electricity, gas.
Enhanced legal separation: represents additional obligations on the ESO that aim to further mitigate any conflicts of interest	**Limited.** Enhanced separation of the ESO without unbundling any functions.	Electricity only.

Strategic planning body: this model unbundles a range of current and net zero system roles from National Grid plc with control centre operation functions performed by National Grid Electricity Transmission (NGET) or NGGT.	**Considerable.** Current and future net zero system roles related to market development and transactions and whole system insight, network planning and coordination would be unbundled from National Grid plc and transferred to a strategic planning body. Electricity control room operations would be performed by NGET. Gas control room operations would be performed by NGGT	Electricity, gas.
Independent System Operation ("ISO"): SO companies are no longer a part of National Grid plc.	**Full.** Unbundling of all current and future net zero system roles from National Grid plc.	Electricity, gas, electricity and gas combined.

3.1.1 Code modifications

To operate within the GB electricity sector, market participants such as generators, suppliers, and traders must comply with several individual, yet often overlapping codes (DECC 2016; Lockwood et al. 2016; Ofgem 2021a). These codes are effectively multi-lateral agreements which state the terms under which participants can operate in the market and access the networks (Lockwood et al. 2017b).

These codes were introduced to provide institutional stability, and the governance of these was delegated to the regulator, Ofgem, and a 'code panel' on which sit prominent stakeholders within the energy sector such as National Grid ESO (Table 8) (Lockwood et al. 2017b). This delegation was founded upon the assumption that industry participants held the most detailed knowledge on how the electricity market operated (Lockwood et al. 2017b). The outcome of code modifications being raised are typically small-scale alterations to the existing rules as a result of a complex and fragmented set of codes and the potential for vested interests on the governing code panels.

There are three established routes to altering a code:

Self-governance (Fast track): This route is intended for minor modifications to the code in question, deemed not to have a material impact. Such modifications can be accepted/rejected by those residing on the code panel and therefore under current governance do not require input from the regulator Ofgem.

Ordinary: This route follows the same procedures as self-governance; however, the panel does not have the agency to decide on whether the proposed modification is accepted or rejected. The panel instead recommends an outcome, i.e. accept or reject, to Ofgem which then makes the final decision.

Significant Code Review (SCR): This route provides a means for Ofgem itself to raise a modification. SCRs are characterised by wide, holistic changes.

The process of code governance has been criticised for a variety of reasons which have been compiled in Table 9. BEIS and Ofgem have consulted on how to improve code governance, but at the time of writing the outcome of this process has not been announced.

Table 8 The main energy industry codes within GB. Source: (Lockwood et al. 2017b).

Area	Title	Description
Electricity distribution	Distribution Code	Technical parameters relating to the planning and use of electricity distribution networks.
	Electricity distribution Connection and Use of System Agreement	Covers commercial aspects of use of electricity distribution network services.
Electricity transmission	Connection and Use of System Code	Framework for connection and use of high voltage transmission system and certain balancing services.
	Grid Code	Technical aspects relating to connections, operation & use of transmission network.
	System Operator/Transmission Code	Defines the relationships between National Grid as system operator and transmission owners.
Electricity balancing	Balancing and Settlement Code	Sets out rules for participating in Balancing Mechanism and for settling energy imbalance.
Electricity retailing	Master Registration Agreement	Rules for retail market processes including electricity registration, change of supplier processes and the Green Deal.
Gas transmission and distribution	Unified Network Code	Defines the rights and responsibilities for users of the gas transportation systems, and provides for all.
Gas retailing	Supply Point Administration Agreement	Sets out the inter-operational arrangements between gas suppliers and transporters in the UK retail market.

Gas and electricity smart metering	Smart Energy Code	Defines the rights and obligations of energy suppliers, network operators and other relevant parties involved in the end to end management of smart metering in Great Britain.

Table 9 Concerns with current code governance. Sourced from (Wren-lewis 2014; CMA 2015c; Lockwood et al. 2017b; BEIS and Ofgem 2019; Mitchell et al. 2019).

Concern	Explanation
Fragmented and complex	As illustrated in Table 8, there is no one organisation with oversight of all code modifications. Yet, a proposal to one code may require subsequent modifications of other codes. This creates a fragmented, and complex landscape to navigate for those wishing to make an amendment. This provides an inherent advantage to those with the resources to navigate this complexity, allowing them to reinforce their agendas as their voices are heard, whilst it can be a barrier to newer entrants without the means to circumnavigate these fragmented complexities.
Incremental changes	Building upon the above, the fragmented set up makes systematic change slow and difficult to achieve. This is at a time when a transformation of the energy sector is required.
Weak incentives to drive timely change	Being industry-led, a lack of interest from industry to enact change can result in a slow, incremental change. This can pose a barrier to those wishing to pursue innovation.
Information capture	Ofgem may require input from industry on the impacts of a modification. Relying on industry may lead to 'informational capture' in which those in industry may only provide partial, selective or misleading information to Ofgem to sway a particular outcome.
Resource intensive	On average, 16 full day workshops are required for each modification. Attendance therefore favours organisations with the resources to send a representative to these meetings, and disfavours participants with limited time, expertise, and/or financial resource to attend these meetings. The costs incurred are higher for the organisation who raises the modification compared to those who attend the working groups as this includes allocating resources to building the case for

	change, approaching the relevant code body(s) and then the attendance of subsequent meetings. As such, an organisation with the resources to raise a modification can also set the agenda limiting the scope to their own perceived issue, evidencing a clear incumbent advantage under the current mode of code governance.
Vested interests	Research by Lockwood et al. (2017b) highlighted that between 8-50% of code panel representatives were employed by one of the large vertically integrated companies. Which Lockwood argues has brought forward vested interests to the panel and may influence the outcome of proposed modifications to favour their business case.

3.1.2 National Grid ESO altering the balancing mechanism and ancillary market

As the operator of the balancing mechanism and ancillary market National Grid ESO, under guidelines laid out by Ofgem and the European Commission, has the agency to enact the process of electricity market re-design for both of these markets. There are several live projects which may lead to alterations.

3.1.2.1 Pathfinder projects

These are a range of projects overseen by National Grid ESO to test and trial new processes to solve long-term challenges for the electricity sector - such as arising from the loss of thermal generation (National Grid ESO 2019b, 2020c). These include:

The constraint management pathfinder: The aim is to provide a commercial product based around constraint management through annual tenders for turn down/demand turn up from transmission connected generation at the B6 boundary[1] (National Grid ESO 2020c, 2020d).

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[1] The B6 boundary is located between England and Scotland and is the most constrained area on the GB network. Further information on this can be found in chapter five, section 5.1.3.

The stability pathfinder: The aim is to review a range of commercial and network solutions to meet stability needs i.e. frequency, voltage and ability of network users to remain connected to system during normal operation, during and after a fault (National Grid ESO 2020c). This includes research into the creation of a market for inertia (National Grid ESO 2020b).

3.1.2.2 Product Roadmaps

Product roadmaps are another means for National Grid ESO to alter the balancing mechanism and the ancillary markets. Launched in 2017, National Grid ESO's 'system needs and product strategy' program which consulted with industry on how to reduce barriers to entry into these two markets (National Grid 2017a). Drawing on feedback, National Grid ESO has begun trialling new means of product procurement, such as the design and intended implementation of reformed reserve products and the creation of a single day ahead response and reserve market (National Grid ESO 2020c).

3.1.2.3 Reform of frequency products

Introduced in chapter two, section 2.2.1.3, National Grid ESO have implemented DC, a new reserve product to aid with their 2025 goal of operating a net zero electricity grid (National Grid ESO 2019c). The process of implementing this product is stated in EU legislation, which required National Grid ESO to follow these steps (The European Parliament and the Council of the European Union 2019; Ofgem 2020b):

1. National Grid ESO must submit a proposal to Ofgem for approval of DC.
    a. National Grid ESO must propose the need for DC in line with Article 26 of the commission regulation (EU) 2017/2195 (European Commission 2017a; National Grid ESO 2020e; Ofgem 2020b).
    b. Within the submission National Grid ESO must submit for the definition and use of DC as a specific product pursuant to Article 26(1). In accordance to Article 26(1) of the guidelines on electricity balancing regulation, the proposal had to include specific information such as (Ofgem 2020b):
        i. Defining the product and time period of use.

        ii. Demonstrate that existing products are insufficient to ensuring security and to maintain the system balance efficiently.
        iii. Demonstrating that the specific products do no create significant inefficiencies and distortions within the balancing mechanism.
    c. Furthermore, National Grid ESO must also consult with industry on the proposed product in accordance with article 10 of the EGBL regulation (Ofgem 2020b).
2. Ofgem approved the proposal for DC in line with the requirements of EGBL and the wider objectives of EU regulation 2019/943.

Therefore, the actual process of altering the market design which National Grid ESO has agency over is not their prerogative alone but requires the approval of Ofgem.

3.1.3 Government enacted alterations: White papers

Within GB, White papers have been used by the Government to propose future legislation and alter the electricity market design. Namely:

- 1989: Electricity Act: used to privatise the electricity sector and establish the Electricity Pool trading mechanism (now superseded) (BEIS 2020b)
- 2001: Utilities Act: Introduced NETA (Legislation.gov.uk 2000)
- 2004: The Energy Act 2004: BETTA has introduced a single wholesale electricity market across Britain by extending the England and Wales market arrangements to Scotland (BEIS 2020b).
- 2013: The Energy Act 2013: Electricity market reform (BEIS 2020b). Introduced 4 key pillars; the CfD, capacity market, carbon floor price, emission performance standard (DECC 2012a).
- 2021: Powering our net zero future: Though there is no explicit change to the current electricity market design stated within this White paper, there are several consultations introduced and the outcome of these may lead to alterations to this institution (HM Government 2020a).

3.1.4 Government: Smaller alterations

Chapter five details the issues stemming from the current electricity market design within GB, one of which relates to the CfD. In short, this subsidy mechanism allows for prices within the wholesale market to fall below zero which is detrimental to the business case for generators not in receipt of a similar form of revenue assurance scheme. BEIS has consulted on how to address this concern, collecting and analysing responses as a means to help understand the trade-offs (BEIS 2020d, 2020a). BEIS's proposal in the consultation, to not pay subsidies when the price of electricity is negative (BEIS 2020d, 2020a), will now be enacted by government (BEIS 2021e). This evidences how the Government can also enact smaller alterations to the electricity market design.

3.1.5 The exchanges: N2EX/EPEXSPOT

Within GB, access into the day-ahead and intraday exchange is facilitated by two NEMO's, N2EX and EPEXSPOT. Both of these exchanges offer products for market participants to procure, such as hourly and half-hourly day ahead and intraday auctions (NordPool 2017; EPEX Spot 2018). The process for new products offered involves consultations held by the ACER and the relevant NEMO.

The outcome of these consultations provides a range of products for each NEMO to consider offering to their consumers (ACER 2020). The NEMO product selection is based upon meeting the expressed requirements of market participants, and every two years each NEMO will consult with market participants to "ensure that available products reflect their needs" (ACER 2020: 3). Furthermore, ACER may also consult on the creation of new products for the NEMOs, through the collection of market participant views.

3.1.6 EU Legislation

As shown thus far, EU regulation has influenced the trading arrangements of their members electricity market design. Figure 13 illustrates several 'packages' brought in by the EU which have impacted the electricity market design within GB. For example, the latest package, the CEP, is aimed at the decarbonisation of energy and the facilitation of better consumer outcomes (European Commission 2016, 2017b, 2019a;

National Grid ESO 2019d; Peng and Poudineh 2019). Overall, as argued by Peng and Poudineh (2019) these packages embody the continued determination to decarbonise, integrating VRE through market-based mechanisms, whilst recognising the role for new technologies such as DSR and storage and new models for coordination. Several of these articles are summarised within Table 10 which contains the implications of several CEP articles on the current electricity market design within GB.

However, the impact of EU legislation on the GB electricity market design and the process of market re-design has become uncertain due to Brexit, with National Grid ESO (2019d) remarking that the nuances of the UK's exit of the EU and the impact on the rights and obligations which will apply once the UK ceases to be a member state remain to be seen.

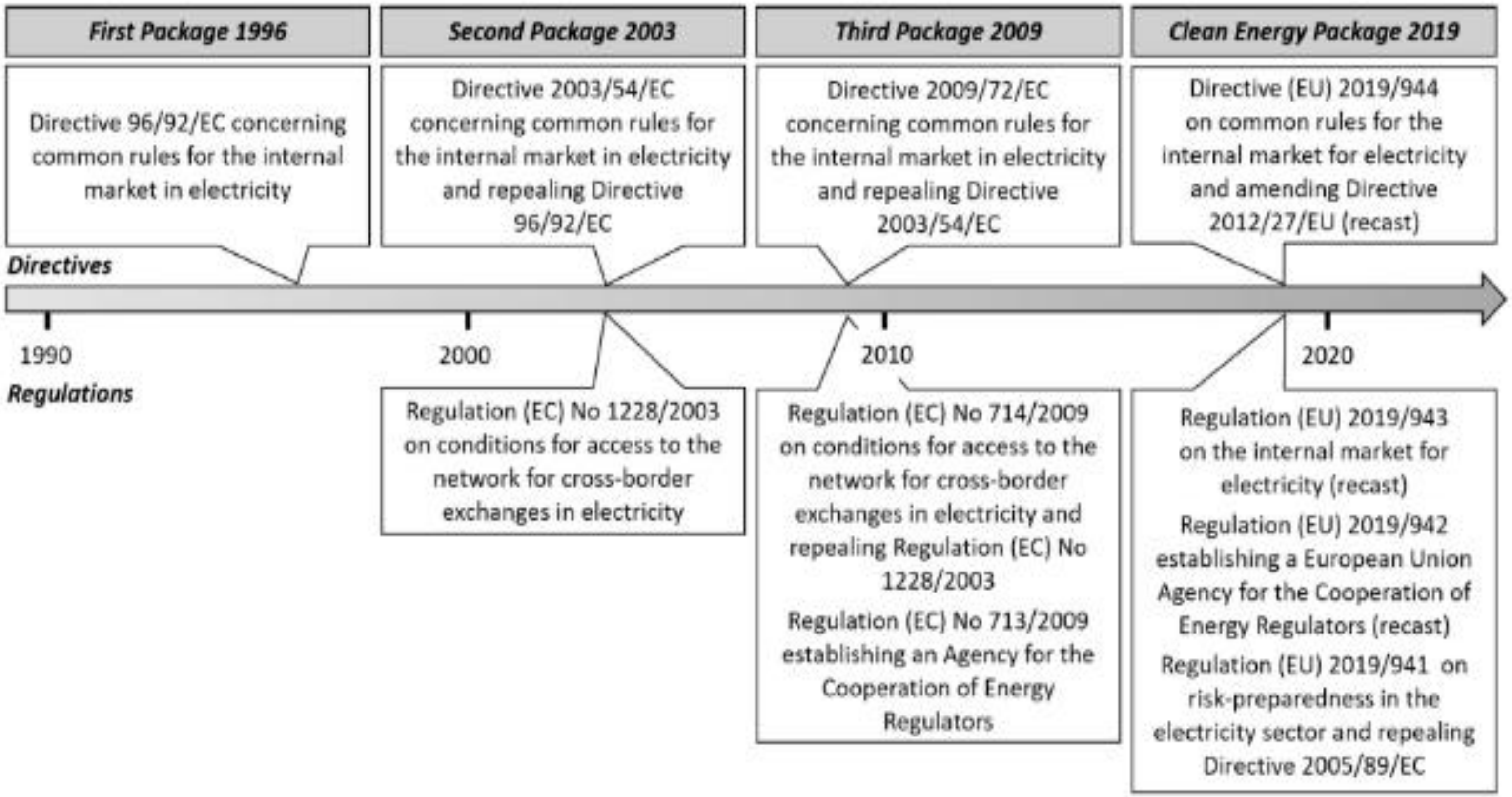

Figure 13 A timeline in the main steps of the evolution of European electricity markets according to Meeus (2020).

Table 10 Articles from the CEP which are leading to alterations to National Grid ESO to alter the ancillary market and the balancing mechanism. Source: (The European Parliament and the Council of the European Union 2019).

Balancing mechanism and ancillary market			
Article	Article Text	Impact	National Grid ESO’s decision
Article 6(2)	The price of balancing energy shall not be pre-determined in contracts for balancing capacity. Procurement processes shall be transparent in accordance with Article 40(4) of Directive (EU) 2019/944, while protecting the confidentiality of commercially sensitive information.	There are current certain products which are contracted which pre-determine the price of balancing capacity (i.e. long-term Short-Term Operating Reserve (STOR), black start).	National Grid ESO has asked for derogation from this article (National Grid ESO 2019e).
Article 6(4)	The settlement of balancing energy for standard balancing products and specific balancing products shall be based on marginal pricing (pay-as-cleared)…Market participants shall be allowed to bid as close to real time as possible, and balancing energy gate closure times shall not be before the intraday cross-zonal gate closure time.	The current set up of the balancing mechanism is based on a pay-as-bid basis. National Grid ESO argue that this shift “has the potential for significant change to our domestic product… our working position is that this change would not be in the interest of consumers” (National Grid ESO 2019e: 8).	National Grid ESO has asked for derogation from this article (National Grid ESO 2019e).

Article 6(9)	Contracts for balancing capacity shall not be concluded more than one day before the provision of the balancing capacity and the contracting period shall be no longer than one day, unless and to the extent that the regulatory authority has approved the earlier contracting or longer contracting periods to ensure the security of supply or to improve economic efficiency.	At the time of National Grid ESO's response to the CEP (National Grid ESO 2019e), there were contracts for balancing capacity i.e. STOR and Fast Reserve which were contracted for more than one day in advance.	Derogation for STOR has been submitted but not for Fast Reserve. The latter product is being phased out with the introduction of a new product suit described in appendix two. No STOR contracts were procured in 2020 as a result of the CEP, with National Grid ESO undertaking work on making STOR compliant with the CEP. STOR is now operational, but contracted at the day ahead stage (National Grid ESO 2021c).

This section has detailed several avenues for electricity market re-design within the current GB institutional framework. It is these examples which provide the focus of applying a theoretical framework which shall be introduced within the following section.

The following section will explore possible theoretical lenses to aid in understanding the process of electricity market re-design. The sociology of markets understands markets as social structures which are characterised by power struggles (Fligstein and Dauter 2007). It is nuances such as these power struggles which must be explored in order to answer the third research question and the following section will introduce and develop an appropriate theoretical framework.

3.2 Theoretical perspectives on electricity market re-design

This section will justify why neo-institutional theory, specifically a combination of historical and discursive institutionalism, provide an appropriate and insightful framework for providing insights and lessons on the process of electricity market re-design.

This section begins with a brief statement on how the process of electricity market re-design is undertheorised, before introducing the fields of institutionalism and neo-institutionalism. Four strands of neo-institutionalism are introduced, explained, applied and critiqued in order to show how two strands of neo-institutionalism - historical and discursive - in combination are suitable for this research. In applying the tenets of both of historical and discursive institutionalism to the various processes of electricity market re-design introduced in the previous section, many comparators can be made between the actual means for implementing change and the key tenets of these theoretical frameworks. This highlights how both historical and discursive institutionalism are applicable to the process of electricity market re-design, and can help to understand the process of this institutional change.

3.2.1 Considerations to other established theoretical frameworks

A review of relevant literature shows that the study of electricity market re-design is undertheorised. Theoretical frameworks which reference ‘markets’ and ‘market design’, such as design economics (Kominers et al. 2017; Roth and Wilson 2019) and the Multi-Level Perspective (MLP) (Geels 2002), can be used to redesign a ‘market’, but they are not appropriate for understanding how to implement a fit-for-purpose electricity market design.

Design economics (also known as market design) has its theoretical roots in the field of Game Theory with those pioneering scholars of design economics field such as Roth (2015, 2018) and Kominers et al. (2017). Under design economics, the ‘market designer’ is assumed to have “the complete freedom to introduce new mechanisms” (Roth 2018: 1646). Roth (2015, 2018) provides examples of undertaking the role of a ‘market designer’, in which he made amendments to a range of ‘markets’, such as the medical labour markets, auctions of radio spectrums and appointing prospective students into schools. In this, design economics can be considered as working out the means for an exchange, rather than focusing on the process of market re-design itself. Second, to assume that the market designer in the context of augmenting GB’s electricity market design would have ‘complete freedom’ disregards the role of lobbying within this process. Third, the characteristics of the markets explored within design economics differ greatly to that of the electricity market, further reducing the efficacy of this framework in the context of this thesis.

The MLP stems from the Science, Technology and Society (STS) literature and is considered to be a seminal framework conceptualising complex socio-technical transitions (STT) (Geels 2002). The MLP accounts for multiple aspects of societal and technological change simultaneously, and many scholars have used this framework to analyse transitions towards sustainability within the energy sector (Verbong and Geels 2007; Loorbach and Rotmans 2010; Fuenfschilling and Truffer 2014). However, the MLP’s focus on the ‘market’ is as a measure of the success of a new technology entering into the regime i.e. becoming a mainstream technology. Within the MLP there are several factors influencing whether a new technology will become mainstream, such as politics, cultures, laws and markets. As such, the MLP provides a useful overview of the process of technological change, yet, due to this broad focus the role of the market, and the process of market re-design, is overlooked.

Therefore, there is a gap within the literature on the theorising on how electricity market re-design occurs, which the following section will address.

3.2.2 What is institutionalism?

The field of institutionalism is characterised by an emphasis upon the institutional context in which political events occur, and the outcomes they generate. In other words, institutionalist approaches seek to better understand the role that institutions play in determining political and social outcomes (Hall and Taylor 1996; Schmidt 2006). For example, Scott (2013) argues that an institutionalist lens would be adopted to answer the following questions:

1. Why do organisation and individuals conform to institutions? Is it because they are rewarded for doing so, because they believe they are morally obligated to obey, or because they can conceive no other way of behaving?
2. How and why do formal and informal control structures arise? Do individuals voluntarily construct rule systems that then operate to bind their own behaviour?
3. If institutions regulate individuals, how can individuals hope to alter the institutions in which they are embedded?

There are many different strands of institutionalism which adopt their own definition of what constitutes an 'institution' as will be evidenced throughout this chapter. That said, Andrew-Speed (2016: 216) draws on the work of prominent economic institutionalists such as Douglas North (North 1990) and institutional theorists such as Richard Scott (2013) to identify what he claims to be an commonly-cited definition of an institution:

> "Institutions have been variously conceptualized as formal and informal rules or as shared self-sustaining beliefs and expectations that may or may not be represented by rules"

It is these institutions which have the capacity to control and constrain behaviour through imposing boundaries be that via defining legalities or setting moral and cultural boundaries which provides a compass for how to act in an acceptable or unacceptable manner (Scott 2013; Becker et al. 2016). These institutions may also empower activities and actors by providing 'stimulus, guidelines and resources' for acting, allowing actors to make decisions with limited institutional guidance and information (Scott 2013; Andrews-speed 2016).

Drawing on this definition of an institution, there is a clear parallel with that of the electricity market design introduced in chapter one, section 1.1, repeated here:

> "[The electricity] market design is the 'rulebook' for energy market players. The rules establish the general principles and technical details on energy market participation, as well as specify rights and responsibilities among market participants. 'Market design' is the 'software' on which our energy markets run, while the energy infrastructure is the 'hardware'" (European Commission 2016: 1).

Both the definition of an institution provided above, and that of the electricity market design, describe being the 'rules' which guide participation, either limiting or empowering the actions taken within a given institution, highlighting how the electricity market design is an institution itself.

3.2.3 'Old' Institutionalism

According to Schmidt (2006), any account of neo-institutionalism would be incomplete without visiting the original pillars of institutionalism. This section will briefly introduce 'old' institutionalism before discussing neo-institutionalism in depth.

The focus of 'old' institutionalism was on the formal institutions of government, defining the state in terms of the political, administrative and legal arrangements, epitomised in the work of Woodrow Wilson, Kant, Hegel and Gustav Schmoller (Schmidt 2006; Scott 2013). Institutionalism was considered a descriptive methodology aimed at explaining the relations among different levels and branches of government with the concept of the state understood in terms of sovereignty, justice, power, citizenship and legal status; drawing from political philosophy (Schmidt 2006). This was thus concerned with processes of the government rather than that of governance.

'Old' institutionalism was critiqued for lacking a social dimension and the informal conventions which shaped institutions (Schmidt 2006). This framework was superseded by approaches emerging within the political sciences in the 1950s and then behaviourism during the 1960s. Within this, the 'state' as a term disappeared from the literature, with 'old' institutionalism being dismissed as only offering a mere description, with Lowndes (2017: 54) arguing that there was "much, much more to politics than the formal arrangements for representation, decision-making and policy implementation".

3.2.4 Neo-Institutionalism

This section provides an overview of the four key strands of neo-institutionalism to demonstrate the differences, and overlaps, between these. The purpose of this is to demonstrate the different strands of neo-institutional theory which are available to study the phenomenon in question. This is followed by a deeper dive into each of the individual strands of neo-institutional theory and assessing their efficacy in understanding the institutional process of electricity market re-design i.e., their ability to aid in addressing research question three.

Beginning in the late 1970s/ early 80s, institutionalism was making a re-appearance, emerging in response to the under-socialised characteristics of both behaviourism and rational choice theory (Schmidt 2006; Scott 2013). A key principle of neo-institutionalism is that behaviour cannot be understood without reference to institutions (Schmidt 2006). In essence, neo-institutionalism involves “bringing institutions back in to the explanation of politics and society”, and the approach has gained increasing scholarly attention across the field of political science and within the study of energy system transitions (Schmidt 2006: 98; Andrews-speed 2016; Kuzemko et al. 2016; Lockwood et al. 2017a).

Political scientists who situate themselves within the field of neo-institutionalism will call upon one or multiple strands depending upon their preferred methodological approach and their epistemological and ontological presuppositions (Schmidt 2010a). While there are several strands of neo-institutionalism, this thesis focuses on the following commonly cited four strands (Hall and Taylor 1996; Campbell 2004; Andrews-speed 2016; Becker et al. 2016):

- Rational choice institutionalism,
- Sociological institutionalism[1],
- Historical institutionalism,
- Discursive institutionalism.

These strands all share basic ontological features, such as envisaging actors - either individuals or organisations - as confined by the institutional frameworks they are

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[1] Also referred to as organisational institutionalism.

operating in (Bell 2011; Andrews-speed 2016; Becker et al. 2016). Schmidt (2010a) presents an overview of the differences and similarities between these four strands (Table 11).

Table 11 An extract from Schmidt (2010a) *which summarises the four strands of neo-institutionalism. Note that each of these strands will focus on either, or a blend, or individuals and organisations within the context of interacting with the institution.*

	Rational choice institutionalism	**Historical institutionalism**	**Sociological institutionalism**	**Discursive institutionalism**
Object of explanation	Behaviour of rational actors.	Structures and practices.	Norms and culture of social agents.	Ideas and discourse of sentient agents.
Logic of explanation	Calculation.	Path-dependent.	Appropriateness.	Communication.
Definition of institutions	Incentive structures.	Macro-historical structures and regularities.	Cultural norms and frames.	Meaning structures and constructs.
Approach to change	Static - continuity through fixed preferences, stable institutions.	Static- continuity through path dependency interrupted by critical junctures.	Static- continuity through cultural norms and rules.	Dynamic change (and continuity) through ideas and discursive interaction.
Explanation of change	Exogenous shock.	Exogenous shock.	Exogenous shock.	Endogenous ideational and foreground discursive abilities.
Recent innovations to explain change	Endogenous ascription of interest shifts through rational choice	Endogenous description of incremental change	Endogenous construction (merge with discursive institutionalism).	Endogenous a construction through reframing, recasting collective memories and

	institutionalism political coalitions or historical institutionalism self-reinforcing or self-undermining processes.	through. layering, drift, conversion.		narratives through epistemic communities, advocacy coalitions, communicative action, deliberative democracy.

There are no ‘sharp boundaries’ between each of these schools of thought, as a number of ideas can be found across two or more strands of neo-institutionalism (Andrews-speed 2016). Each of these strands can thus contribute to research in different, yet complementary ways (Becker et al. 2016). Figure 14 situates several scholars in their use of a neo-institutional framework, and as can be seen, many scholars have utilised two strands of neo-institutionalism in tandem to satisfy their conceptual requirements.

This section is laid out as follows, each of the four strands of neo-institutionalism will be introduced and explored in relation to providing a theoretical framework for the process of electricity market re-design.

The first two strands to be introduced are rationale choice and sociological institutionalism. These strands are briefly explored, and the reasons detailed in their respective summaries highlight how they are not suitable frameworks for the study of electricity market re-design. The two suitable frameworks, historical and discursive institutionalism, are then discussed in more depth.

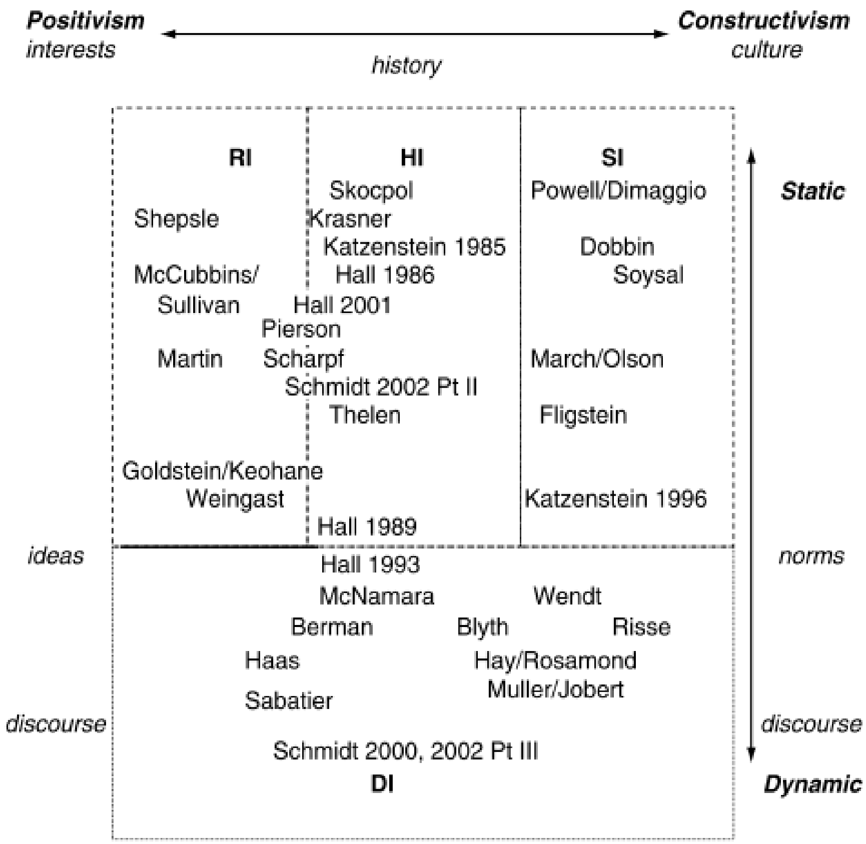


Figure 14 Scholars use of the four strands of neo-institutionalism according to Schmidt (2006). *RI = rational choice institutionalism, HI = historical institutionalism, SI = sociological institutionalism and DI = discursive institutionalism. Note that several authors are attributed to being on the cusp of two different strands, drawing upon facets of both to understand a particular phenomenon. Source: (Schmidt 2006).*

3.2.4.1 Rational choice institutionalism (RI)

RI is underpinned by the assumption that actors are rational. However, the rationality of these actors is bound by institutions which provide incentives, or rules, to create order (Andrews-speed 2016). Within this realm, actors are viewed as seeking to pursue their fixed rationalist preferences (Schmidt 2008).

In relation to defining an institution within RI:

> “institutions are conceptualised largely as sets of positive (inducements) and negative (rules) motivations for individuals, with individual utility maximisation providing the dynamic for behaviour within the models” (Guy 1999: 45)

RI has relevance as a lens for the present study, Schmidt (2006) argues that such a lens can identify the interests and motivations of rational actors within a given institutional setting. The deductive nature of this approach is useful to capture a range of reasons for why a rationale actor may have taken a particular action within a given institutional structure, helping to predict likely outcomes as well as identifying anomalies or unexpected actions (North 1990; Andrews-speed 2016).

RI is not without its drawbacks, and Schmidt (2006) and Green and Shapiro (1994) argue that it is unable to explain behavioural anomalies when they depart from the interest-motivated action. Moreover, due to the fixed preferences and a focus on equilibrium conditions, RI suffers from a limited account for why institutions change over time, struggling to explain change other than when purely functionalist (Hall and Taylor 1996).

Secondly, RI typically offers a high level of abstraction, which in turn provides a 'thin' definition of rationality and a 'simplistic' understanding of human motivation (Mansbridge 1990; Schmidt 2006). As the electricity system is highly political, the motivations behind an actor's decisions to enact electricity market re-design through the established routes in section 3.1 may not be fully accounted for under this strand of neo-institutionalism. As such, this may underplay actors' motivations for affecting change in an electricity market design.

3.2.4.2 Sociological institutionalism (SI)

SI emerged in the late 1970s, evolving from the field of sociology. It rejects older methodological approaches such as behaviourism, system approaches and rational choice analyses (Schmidt 2006).

SI takes the view that institutions consist of norms, cognitive frames and meaning systems which guide human action according to culturally specific logic which determines what is 'appropriate'. In this context, SI is an example of a framework focused on institutions for individuals, rather than organisations. Consequently, SI highlights the importance of culture in establishing the nature of institutions, and the way in which these shape actors' behaviour (Schmidt 2006; March and Olsen 2008; Andrews-speed 2016). This contrasts with RI's view that human behaviour follows an objectively rational self-interest, as rationality for sociological institutionalism is socially constructed, and culturally and historically dependent (Schmidt 2006). It is these cultural institutions which bound people's imagination and establish basic preference (Schmidt 2006).

Institutions within SI can include symbols, frames and values which determine the practices that are specific to a particular culture. In turn these may not have a relationship to economic efficiency (Andrews-speed 2016). This has been summarised as "appropriateness trumps performance", with actions primarily aligning to a particular culture, with efficacy a secondary driver (Hall and Taylor 1996; Andrews-speed 2016: 219).

As with RI, there are advantages to applying SI as a theoretical lens in this research. SI has been cited as beneficial for researchers wishing to delineate the shared understandings and norms that frame action, shape identity, influence interests and affect the perception of problems and the identification of solutions (Scott 2013).

Conversely, this approach has been criticised by Schmidt (2006) for being too specific, with the knowledge it provides only valuable as a steppingstone to conducting research within a RI framework. Furthermore, Kern (2009) criticises the approach's strong focus on rule-following, instead of processes of rule-creation, and the limited ability of the lens to account for contentious political processes.

Despite the merits of adopting a SI framework, there are limitations to applying SI to the process of understanding electricity market re-design. Firstly, the definition of an institution within SI is not appropriate for an electricity market design which is encoded in legal text, rather than embedded in symbols or norms. Secondly, within GB's electricity market design there is no culturally specific logic which determines what is 'appropriate', as the correct means of acting within the market design are also stated within these legal texts. As such, the SI approach is not considered to be an appropriate framework for addressing the third research question.

That said, this is not to say that the SI approach could not be applied to other aspects of study within the field electricity market design. One of the cited merits of adopting a SI framing is to understand the values that determine a particular outcome (Hall and Taylor 1996; Andrews-speed 2016). This may be a particularly useful framing as GB's electricity system becomes increasingly decentralised, with the ownership of assets and how they operate being determined by the end consumers ideals which may not be focused on economic gains e.g., suppling excess solar PV at a discounted price to a local community centre.

3.2.4.3 Historical institutionalism (HI)

HI has been argued to be the strand of neo-institutionalism most influenced by the 'old' institutionalism alongside structural-functionalists and Marxists (Schmidt 2006). For example, the focus on the state and formal institutions of government is common to both HI and a structural-functionalist approach. Power, on the other hand, is conceptualised akin to Marxist theory as capable of structuring character and outcomes of conflicts (Hall and Taylor 1996; Schmidt 2006; Fligstein and Calder 2015).

HI calls upon a broad definition of an institution, considered in this context as both the formal structures and informal rules and procedures that structure conduct whilst also referring to the importance of norms and routines (Steinmo and Thelen 1992; Andrews-speed 2016). According to HI, the relationship between institutions and the behaviour of groups is affected by the institutional shaping of behaviour and norms, taking into account that actions are also constrained through power asymmetries (Thelen 2002; Scott 2013; Lockwood et al. 2017a).

It is within this relationship that HI attempts to illuminate how political structures are "mediated by the institutional setting [in] which [they] take place" (Steinmo and Thelen 1992: 2). Importantly, political systems are not considered neutral arenas in which interests compete, but complex forums which generate independent interests and advantages, and in which rules and procedures exert important effects on the business being conducted (Scott 2013). HI can thus be seen as a theory of action within institutional constraints in which the outcomes stem from struggles which reflect inequalities of power (Steinmo and Thelen 1992: 2; Hall and Taylor 1996; Campbell 1998; Scott 2013; Lockwood et al. 2017a). In summary, HI "emphasizes that political arrangements and policy feedbacks actively facilitate the organization and empowerment of certain groups while actively disarticulating and marginalizing others" (Thelen 1999: 394). The HI interpretation of institutions as complex arenas which generate advantages for specific individuals over others will help to elucidate how power struggles may emerge in response to the implementation of augmentations to GB's electricity market design.

Both ‘institutional constraints’ and ‘power asymmetries’, will likely alter the process of electricity market re-design – for example the powerful role of vested interests is a criticism of the current code governance process (Table 9). That said, institutions are not always seen as constraining the behaviour of an individual, but may also empower them via the provision of stimulus, guidelines and the resources for acting as well as setting out prohibited actions (Scott 2013). As such, according to HI, institutions may enable the process of electricity market re-design if the institutional set up is geared towards this. It is therefore clear how an HI approach can be applied to aid in conceptualising and framing the process of electricity market re-design.

The HI literature describes numerous advantages, including its focus on the sequences in the development, timing of events and phases of political change (Hall and Taylor 1996; Thelen 1999; Schmidt 2006; Becker et al. 2016; Lockwood et al. 2017a). For example, it emphasises the importance of asymmetries of power related to the operation and the development of institutions (Hall and Taylor 1996; Thelen 1999; Schmidt 2006), highlights path dependencies and unintended consequences that stem from historical development (Schmidt 2006; Becker et al. 2016), and shows how historical decisions may shape and limit the room to manoeuvre in the future (Hall and Taylor 1996; Thelen 1999). As such, HI offers a range of tools to aid in the explicit analysis of institutional dynamics within energy transition. These tools are useful for raising questions about whether specific institutional arrangements are conducive to rapid sustainable transitions within energy systems (Moe 2016; Lockwood et al. 2017a).

There are authors who are critical of such an approach. Scott (2013) criticises the use of HI for its focus on historic, and often single cases. Lockwood et al (2017a) argues that unlike the MLP, HI does not engage with the actual physical technologies themselves. Furthermore, there are authors who critique HI for not paying sufficient attention to the role or ideas by individuals or organisations and their influence on institutional change (Campbell 1998; Olsen 2009; Schmidt 2010b). Whilst HI captures continuity, the framework is less capable of clearly explaining the causes of crises where change happens (Schmidt 2006). It is also considered to lack the tools to clearly analyse how change is implemented, something only partly addressed by Thelen’s work on mechanisms (Thelen 2002; Schmidt 2006). HI is more capable explaining institutional stasis and continuity rather than change (Bell 2011).

Theorising institutional change within historical institutionalism

Historical institutionalists are also interested with how institutions are formed and evolve. While RI frames institutions as "efficient, equilibrium arrangements", HI emphasises the limits to an optimal institutional design, i.e. institutional arrangements are not perfect (Lockwood et al. 2017a: 12). These imperfections arise from multiple sources including how, during the design of an institution, actors who have had limited time to design institutions making decisions which lead to unanticipated consequences (Clemens and Cook 1999; Pierson 2004; Lockwood et al. 2017a).

HI tends to rely on a discontinuous model of change in which change occurs gradually, but is periodically punctuated by moments of agency and choice, known as 'critical junctures' (Mahoney and Thelen 2010a; Schmidt 2010a). These critical junctures are defined as moments in which the dominant "constraints on actions are lifted or eased", allowing for agency, and a deviation from the present pathway (Capoccia and Kelemen 2007; Mahoney and Thelen 2010a; Andrews-speed 2016). A sufficiently large crisis of confidence in the efficacy of the current institution can even cause the wholesale replacement of one institution by another (Andrews-speed 2016). These crises can last for several years as society experiments with new institutions before a new equilibrium is found (Andrews-speed 2016). The occurrence of multiple critical junctures over time creates a pattern of punctuated equilibrium (Kingston and Caballero 2009).

In relation to how HI theorises gradual institutional change, Table 12 summarises the four-fold characterisation of gradual change proposed by Streeck and Thelen (2005) and built upon by Mahoney and Thelen (2010a).

As explained by Lockwood et al. (2017a), both drift and conversion require neglect or reinterpretation of the existing rules, instead of the introduction of new rules as is the case with layering and displacement (Streeck and Thelen 2005; Mahoney and Thelen 2010a). However, within the energy sector, many institutional rules, due to the criticality of this sector are enshrined in legislation and digression can bring repercussions, such as financial penalties; as such both drift and conversion are unlikely to occur and are therefore unsuited to theorising institutional change within an electricity market design (Lockwood et al. 2017a).

Table 12 Four models of institutional change. Adapted from (Thelen 2009; Mahoney and Thelen 2010a).

Type of change	Description	Removal of old rules?	Neglect of old Rules?	Changed impact/enactment of old rules?	Introduction of new rules?
Layering	Layering is defined by the addition of new rules to an existing institution. This does not result in the replacement of the existing rules, but an amendment to them.	No	No	No	Yes
Drift	Drift occurs as a result of rules remaining the same, but their impact is altered due to an external shift (Hacker 2005). This is when actors knowingly decide not to respond to an external change, and their inaction can change the institution.	No	Yes	Yes	No
Conversion	Conversion occurs when the rules of the institution remains the same, but are interpreted in different ways than its intended meaning (Thelen 2003). This is not driven by external change as is the case with Drift, rather by actors exploiting ambiguities of the	No	No	Yes	No

	institutions, converting the rules to serve a new function, or goal.				
Displacement	This when the existing rules are replaced with new ones, which can be abrupt, or, incremental if the new institutions come in and compete with the existing institutions, rather than supplementing them as described the in three above. This form of institutional change is argued to be rare within contemporary advanced capitalist economies due to its disruptive nature.	Yes	N/A	N/A	Yes

The efficacy of GB's electricity market design, based on the facilitation of the four key objectives of this institution as defined in chapter two, section 2.3, diminishes overtime due to both internal and external environmental pressures. Drawing upon the organisational management literature, where the environment is considered the patterns of external conditions and influences that affect the phenomenon in question; these influences can be classified into five dimensions: technology, economic, physical, social and political each of which can impact upon the efficacy of the market design (Andrews 1971; Suarez and Oliva 2005). Therefore, institutional change will need to continuously occur to keep this institution up to date with the wider energy system (Andrews 1971; Pierson 2000; Suarez and Oliva 2005; Pierpont and Nelson 2017a). Figure 15 illustrates the differences between layering and displacement events.

Introducing institutional change by layering or displacement is argued to be influenced by the presence of strong veto possibilities (Figure 16) (Tsebelis 2002; Lockwood et al. 2017a). This 'veto' is held by what Tsebelis (2002: 19) defines as the 'veto player', an "individual or collective actors whose agreement is necessary for a change in the status quo". The relevance of the veto player, in terms of how to implement augmentations to GB's electricity market design is apparent when considering whether such a body would agree to or resist the implementation of said augmentations. In the context of the GB energy sector, veto players would include both BEIS and Ofgem (Lockwood et al. 2017a), or possibly an incumbent. Ofgem, with its considerable veto powers, is able to proceed in developing a more sustainable energy system on its terms and at its own pace (Lockwood (2016) – thus highlighting the importance of those with the veto possibility. As summarised by Lockwood et al (2017a: 13) "while reformers may be able to introduce new rules, if there are actors in existing institutions with strong veto possibilities, they are more likely to resist displacement, leading to layering".

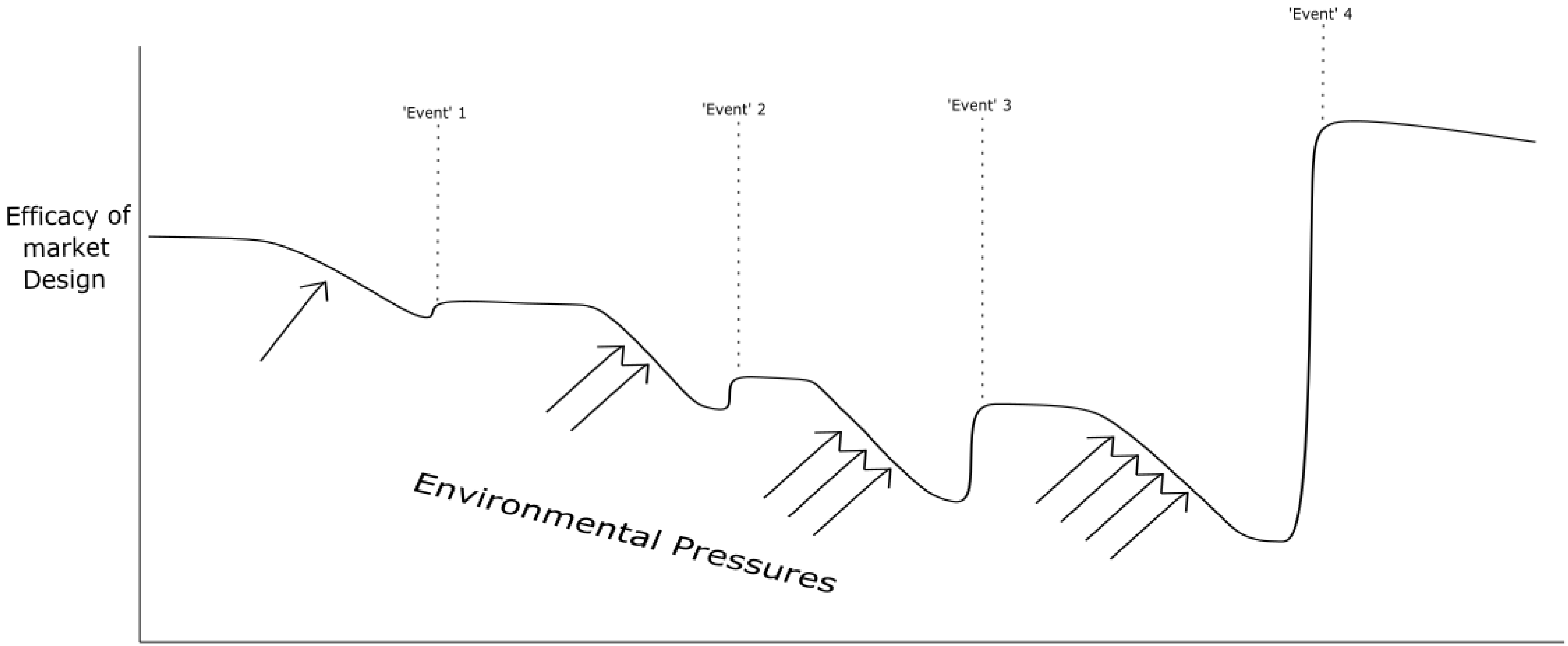
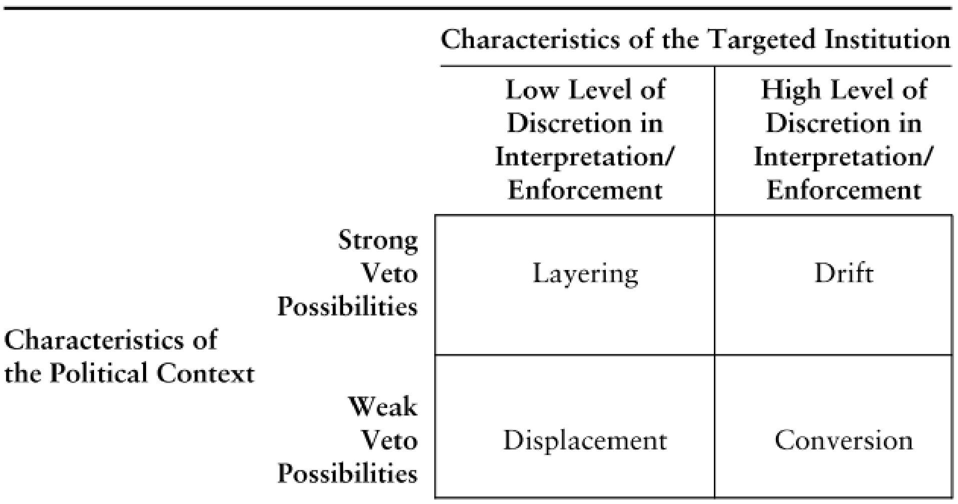


Figure 15 Authors illustration of the processes of layering and displacement. Events 1-3 represent 'layering', in which additional rules are added to the existing. These can range in the size depending on what is being implemented. For example, a code modification could be Event 1, whereas the EMR would be Event 3, but always incur the addition of rules. Event 4 illustrates a displacement event where the rules are replaced with new ones.



		Characteristics of the Targeted Institution	
		Low Level of Discretion in Interpretation/ Enforcement	High Level of Discretion in Interpretation/ Enforcement
Characteristics of the Political Context	Strong Veto Possibilities	Layering	Drift
	Weak Veto Possibilities	Displacement	Conversion

Figure 16 Contextual and institutional sources of institutional change. Source: (Mahoney and Thelen 2010).

As a displacement event which removes the existing rules entirely would fundamentally alter how participants within this institution are to act; this brings considerable risk to actors' position and sunk investment and may therefore be resisted. Layering meanwhile introduces change but without displacing the current rules and so reduces the impact on sunk investment and user practices. There is clear evidence of layering events occurring within GB's electricity market since NETA, which is systematic considering the incremental alterations which can be made under code governance.

3.2.4.4 Discursive institutionalism (DI)

DI, also referred to as ideational institutionalism, constructivist institutionalism and economic constructivism, is often considered to be the 'fourth' strand of institutional analysis[1] (Schmidt 2006; Becker et al. 2016; Lockwood et al. 2017a). This strand grew out of concerns that the three alternative strands underplayed the importance of ideas and agency in explaining how institutional changes occur (Blyth 2003; Schmidt 2006; Bell 2011). Instead, DI provides an account of how institutional change occurs by focusing on the dynamics of actor preferences, interactions and the development of ideas (Schmidt 2008; Lorenzoni and Benson 2014).

Within DI, institutions are not considered to be external, rule following structures (Schmidt 2008). Instead, institutions are considered to be the internal

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[1] Whilst DI is often considered the 'fourth strand', there is a debate within the institutional literature regarding whether DI might be better incorporated into HI. This debate is briefly explored in section 3.2.9.

structures and constructs available to those with ideas within a given context to explain how institutions are created and maintained, and through discursive abilities how institutions change.

At its core, DI takes "ideas and discourse seriously", and as such institutions shape behaviour primarily through the frames of reference which they themselves embody, and the ideas and narratives used to explain and legitimise political action (Schmidt 2006, 2010c: 1; Lowndes 2017). Within DI, ideas can be placed into three levels; Policy, programme and philosophy (Schmidt 2006; Lorenzoni and Benson 2014):

- Policy ideas shape the options and solutions to a particular issue
- Programmic ideas are the underlying principles of policy which include the defining of the problem
- Philosophical ideas encompass the deep-seated ideas, such as worldviews which are rarely discussed nor contested

These ideas are seen by Schmidt (2006, 2010c) as a means to construct the institutional structures and the process of institutional change via the interaction of actors and the making sense of the world around them.

Within DI, a discourse is considered the process of generating ideas, their acceptance, support, legitimation and communication of ideas (Lorenzoni and Benson 2014). Lorenzoni and Benson (2014) suggest that these processes are interlinked with the introduction of new institutional practices and norms (Lorenzoni and Benson 2014). Therefore, to explore the development of institutions will require an understanding of how these ideas have become codified over time and the conditions in which these ideas are "contested, challenged and replaced" (Hay 2002: 65).

The key merit of DI is that is offers an explanation of the dynamics of change, and also continuity, as arising from ideas and discursive interactions, new or continuing (Schmidt 2006). Yet, there are several concerns reported within the literature on taking a DI framework by both Schmidt (2006) and Bell (2011). In its attention to ideas and discursive interactions, DI largely excludes the economic, historical nor cultural determinism of the three other strands of neo-institutionalism (Schmidt 2006). As such, there is a risk that DI may appear highly voluntaristic in theorising institutional change unless the tenet(s) of fellow strand of neo-institutionalism is included (Schmidt 2006);

that DI places too much emphasis and explanatory weight on agency, losing sight of the importance of institutions (Bell 2011); and that the framework concedes too much to the importance of ideas and has stated little on where ideas, meanings and norms originate from and how these are shaped and changed (Bell 2011).

3.2.5 The role of path dependency and positive feedback loops

The field of HI emphasises that historic decisions made in the past play a crucial role in determining future policy via path dependency (Kern 2009; Becker et al. 2016: 33; Lockwood et al. 2017a). These institutions, once established, have a "continuing effect on subsequent decision-making and institution-building episodes" and therefore current choices and possibilities are 'constrained' and 'conditioned' by historical decisions (Campbell 2004: 25; Scott 2013).

The seminal work of Unruh (2000, 2002), Foxon (2002) and Seto et al. (2016) highlights that within the field of path dependencies there is a branch known as 'carbon lock-in'. Carbon lock-in is considered to be the path dependent process in which positive feedback loops, summarised below, inhibit innovations and competitiveness of low-carbon alterations, locking in societies to a fossil-fuel regime (Unruh 2000, 2002; Foxon 2002; Erickson et al. 2015; Seto et al. 2016). This form of path dependency, they argue, is common within complex systems; such as a nation's electricity system. These authors argue that carbon lock-in can be split into three fields; technological, behavioural and institutional. The latter is associated with the governance, institutional setting and subsequent decision-making which impacts upon an electricity sector and is therefore of direct relevance for this thesis. The introduction of a capacity market within GB as explained in chapter two, section 2.2.1.4 offers an example of institutional carbon lock-in due to the continued financial compensation for fossil fuelled generation via long-term contracts.

Over time, continued progress by stakeholders of the energy system along a certain trajectory can lead to positive reinforcement within the paradigm due to cumulative advantages; this, in turn, strengthens preferences in favour of the prevailing paradigm and increases the likelihood and intensity of resistance to attempts at change (Pierson 2000; Seto et al. 2016). This could pose as a barrier to the augmentation of an electricity market design. Once rules have been introduced, removing these are difficult as a result of politician’s short time horizons, and their preference of continuing with the status quo, even if these are seen to favour the continued use of fossil fuels (Pierson 2000; Seto et al. 2016).

A review of previous works on path dependency and the associated positive feedback systems identifies five aspects of resistance to institutional change which may block proposed augmentations to an electricity market design (Arthur 1994; Pierson 2000; Hall 2010; Bell 2011; Scott 2013; Seto et al. 2016; Lockwood et al. 2017a):

- High entry costs to challenge the status quo as once an approach is established, the development of an alternative model and the means to challenge the existing regime (i.e. via code governance) can be resource intensive.
- Self-reinforcement measures make reversal increasingly tough as investors have aligned to the current institutional rules and have sunk costs based upon them and will be reluctant to consider alternatives.
- As multiple users adopt the same set of practices, there is a ‘coordination effect’ which brings forward advantages such as efficiency in operating within the institution.
- Latecomers to an institution will perceive that a particular approach is widely accepted and are therefore more likely to adopt this approach themselves.
- Actors who have political power within the status quo can use this to alter the rules of the game to enhance/maintain their position of power.

During times of institutional change, the role of ‘power’ and ‘agency’ becomes increasingly visible as theorised within HI (DiMaggio 1991; Scott 2013). Quoting DiMaggio (1988: 13):

> “[T]he form that the resulting institution takes depends on the relative power of the actors who support, oppose, or otherwise strive to influence it”

Building upon this, Scott (2013) and Greif (2006: 380) argue that those in possession of power will seek the authorisation and legitimation to exercise this power and as “institutions affect the timing and nature of institutional change and influence the details of new institutions”, in other words those with power can shape an institution to their advantage. In such instances, those with capabilities to shape the institution can further reinforce and embed themselves within it. This is the path dependent nature of institutional change within the HI framework (Greif 2006). This adds to the reinforcement and positive feedback systems which leads to minor alterations of an institution which in turn provides longer timescales for incumbents with power to hold onto and shape the institutions to better suit their needs whilst reducing the scope for their competition (Scott 2013; Seto et al. 2016).

The need for significant augmentations to GB's electricity market design requires an escape from the current carbon lock-in. Insights on how to do so are provided by the work of Unruh (2002) and Seto et al. (2016) who both argue that exogenous shocks are fundamental to opening up opportunities for institutional change. The need for an external shock for institutional change to occur was also highlighted in RI, SI and HI (Table 11). These shocks provide windows of opportunity for policy entrepreneurs to promote carbon reducing policies to a greater degree of success. Additionally, government themselves can aid in escaping carbon lock-in through implementing proactive strategies to support the move away from the present fossil fuelled regime (Seto et al. 2016). One could consider the UK's legislation of a net zero power sector by 2035 as a step towards escaping the current carbon lock-in; in providing the precedent to explore and implement alternative institutional arrangement to aid in the facilitation of this objective.

3.2.6 Theorising institutional change within discursive institutionalism

Within DI, ideas and discourses are seen as integral causal factors in institutional change and stasis, with change occurring at punctuated moments within a broader process of social learning (Blyth 2002; Fuller 2010; Moss et al. 2015).

DI offers an account of how institutional change occurs via the dynamics of actor preferences, interactions and the development of ideas about how an institution should be structured (Blyth 2002; Schmidt 2008). Furthermore, both Blyth (2002) and Schmidt (2012) argue that as actors lose their faith in current institutions as existing institution no longer promote their expectations, they gain new ideas on how this institution could be operated. DI therefore posits the importance of actors in implementing institutional change.

Visualised by Schmidt (2006), these ideas behave as ‘switches’ which funnel interests down a specific policy direction, acting as filters and focal points or lenses to provide policymakers with strategies. This highlights the importance of how ideas become codified over time through processes of contestation and displacement (Becker et al. 2016). Due to the importance of ideas, there are clear policy implications stemming from the inclusion and exclusion of actors in the policy process, the identification of solutions, and structuring which voices are heard, i.e. why some ideas dominate the debate, whilst others aren’t included (Schmidt 2008). A view also found within HI with the role of power in determining who is able to influence the outcome of institutional change. For example, in Ofgem’s 2019 5-year review of the capacity market, they consider setting up a ‘Capacity Market Advisory Group’ comprising of industry stakeholders to “assist in developing, scrutinising, and scoping potential proposals before they are submitted to Ofgem. The creation of the group will enable us to effectively utilise industry expertise” (Ofgem 2019a: 5). This appears to mirror the current self-governance route to code modifications, and therefore those on this panel will have the agency to enact, or reject, change; a decision which could be influenced by any vested interests.

Many of the routes to altering GB’s electricity market design require consultation with industry. Yet, as discussed in section 3.1, there is a concern over regulatory capture with those who have greater resources being able to influence policy direction. This regulatory capture can materialise during the various mediums in which stakeholder views are collected. This issue is compounded in how these events are often dominated by incumbents with the resources to engage with these debates, whilst the views of newer market participants who can bring forward innovative solutions due to experiences gained in operating new business models are often marginalised. In excluding their views, the ‘funnelling’ of policy ideas and proposed solutions will be dependent on who is present; typically those with the resources to expend. In acknowledging this, DI asserts that under a scenario akin to that presented above, the veto player holding the event, i.e. Ofgem, must ensure that the views of stakeholders not present must be collected before a final decision is made.

3.2.7 Applying the tenets of historical and discursive institutionalism

There is a clear relevance of both the HI and DI approach in framing how the electricity market undergoes re-design within GB. Table 13 provides an overview on the how the key tenets from both strands of neo-institutionalism can be applied to the existing processes of electricity market re-design.

The applicability of these two theoretical frameworks are applied within chapter seven to aid in providing insights on initiating contemporary electricity market re-design within GB.

Table 13 Several key tenets of both historical and discursive institutionalism and how these can be applied to examples of electricity market re-design within GB.

Historical institutionalism	
Tenet of historical institutionalism	**Examples from this thesis to demonstrate applicability**
Path dependencies	Continuation of the current capacity market regime.
Gradual change (Layering)	Code modification process set up for small-scale alterations to the existing rules.
Replacement of existing rules (Displacement)	The introduction of NETA.
Political systems not being neutral arenas	Code governance which evidences how a political arrangements actively facilitate the organization and empowerment of certain groups while actively disarticulating and marginalizing others.
Power asymmetries	Role of vested interests by those with the resources to enact market rule changes via current code modification governance.
Discursive institutionalism	
Tenet of discursive institutionalism	**Examples from this thesis to demonstrate applicability**
Role of ideas within institutional change	A variety of means for introduction electricity market re-design within GB include the collection of views and ideas from interested parties e.g. consultations.
The power of ideas	Ideas can lead to fundamental change to an institution. This can be exemplified by the Conservative party’s privatisation ambitions, which as discussed in Chapter 2, section 2.1 contributed to a significant reform to GB’s electricity market design.
How an idea has been ‘contested, challenged and replaced’	Code governance is based on new ideas from interested parties being raised as a means to rectify an identified issue. During these meetings these raised ideas are contested and challenged.

3.2.8 Exploring the notion of ‘fit for purpose’ in the proposed theoretical framework

Within the academic literature cited within the previous sections, there is no explicit mention of the term ‘fit for purpose’ in regard to institutional change in either HI or DI. However, there are clear parallels which can be drawn between both strands and the theme of altering an existing institution to become fit for purpose.

HI emphasises restricting factors within the process of institutional change stemming from positive feedback loops, path dependencies, the role of vested interests and the outcome of power struggles. These in turn are tools which can be applied to the process of electricity market re-design to understand the barriers which will impede the facilitation of augmenting the current electricity market design in GB to one which is fit for purpose.

DI promotes the role of ideas and discourses in bringing forward alternative institutional structures in order to address and identified issue with the current arrangements. Similarly to HI, the tenets of DI can be applied to better understand the process of institutional change, and the importance of recognising and incorporating ideas and discourses within this process of institutional change. Though the term ‘fit for purpose’ is not explicitly mentioned by discursive institutionalists, it is clear that such a framework can aid to improving an institution to facilitate this objective. Lessons from this strand of neo-institutionalism can be applied to the process of electricity market re-design to ensure that the process of change draws upon the diversity of experiences and not just those with the resources to maintain the status quo. This in turn will contribute to this institution being considered fit for purpose.

3.2.9 Overcoming shortfalls of historical institutionalism by incorporating tenets of discursive institutionalism

It has been argued that there is no single perfect theory for a research project (Grant and Osanloo 2014) and as can be shown by Figure 14 as several authors found themselves aligning between two-strands of neo-institutionalism to provide them for the required lens for their study; for example Hall 1989, 1993 aligning between DI and HI. This section will explore how shortfalls of HI can be addressed by adopting HI and DI in tandem: two strands neo-institutionalism which some have argued are in fact too similar to be considered separate strands of neo-institutionalism (Bell 2011, 2012; Schmidt 2012).

One criticism of HI has been how this framework underplays the role of agency[1] and ideas in the process of institutional change; adopting a DI lens offers a means to address this shortfall (Schmidt 2006; Becker et al. 2016). Within DI, ideas are critical to how change to an institution occurs through influencing narratives and the importance of agency in conveying actor preferences for how an institution should be designed, thus mitigating the concern that HI underplays the role of agency.

A wider debate has occurred within the neo-institutional literature as to whether DI is already a part of HI. Stephen Bell (2011, 2012) argues that both HI and DI should not be treated as separate strands of neo-institutionalism, rather, DI can be readily incorporated into the HI framework, a view opposed by Vivien Schmidt (2012).

> "being labelled as historical institutionalism or as [discursive] institutionalism is not particularly important. What is important is the appropriate synthesis of explanatory elements" (Bell 2011: 906).

The nuances of such debate are outside the scope of this literature review, yet, whichever side of the debate one may align with, what is important is that elements of DI (namely the importance of ideas and agency within institutional change) are considered by some to complement the HI approach.

Therefore, the proposed conceptual framework is labelled as an HI-driven framework which draws upon insights from DI.

3.3 Chapter conclusions

Theoretical frameworks for the process of electricity market re-design are currently underdeveloped. Section 3.2.1 introduced two established theoretical frameworks, the MLP and Design Economics to evidence a wider review of the literature in order to back up the assertion made that a bespoke framework for electricity market re-design is underdeveloped. This chapter identified several potential theoretical

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[1] One may contest the statement that HI does not take agency into account, based upon the role of the 'veto player' as introduced and described earlier within this section.

frameworks which could guide the process of electricity market re-design within GB and assessed their applicability. Applying the tenets of HI and DI to the processes of electricity market re-design within GB identified how this combined framework provides insights into the process of implementing contemporary electricity market re-design. This framework will be utilised in chapter seven.

4.0 Methodology

Chapter three identified a suitable theoretical framework for the exploration of electricity market re-design to address the third research question 'What recommendations to policymakers can be identified to aid the process of electricity market re-design?'. This chapter will outline and justify the methodological approach employed to address the aims and research questions of this thesis. This includes the process of designing the strawperson electricity market design, the various means employed to validate and appraise this design and how the data collected was analysed, guided by themes identified within the theoretical framework from the previous chapter.

4.1 Initial summary of the research elements

In answering the three research questions a five-stage approach was employed. The stages are described below, and Figure 17 illustrates the iterative nature of this process. The five-stage approach enabled the incorporation of new narratives emerging from the literature, interviews and work undertaken in external projects. This provided the means to critique the assumption(s) of the researcher.

- **Stage one:** The first step was to establish the state of knowledge on the topic of GB's electricity market design informed by a thorough literature review alongside the attendance of conferences and training events.
- **Stage two**: The design of the strawperson was built upon the insights from stage one and a review of 49 papers with proposals for electricity market reform. Aspects of these were incorporated if they were believed to aid in the facilitation of the objectives and the goals of this institution. This process involved the breaking down of GB's electricity market design into 'modules' (e.g. the wholesale market module and the balancing mechanism module) to evaluate the efficacy of each of these and how these modules interact with each other. The term 'module' is defined, and its use justified within section 4.5.2.
- **Stage three**: The strawperson design was critiqued and lessons on market re-design were gathered via 41 semi-structured interviews held with key stakeholders across both GB and Denmark. Further views were gathered via the

presentation of research at both national and international conferences. In addition, views from industry stakeholders expressed at events as part of additional projects conducted alongside this PhD were noted and integrated into the data collection for this PhD (Sandys and Pownall 2020).

- **Stage four**: The data consisted of transcripts from interviews and stakeholder events which were coded and analysed with the assistance of the software NVivo. The codes themselves were inferred from the key themes of the theoretical framework proposed in the previous chapter and the key aspects of each research question.
- **Stage five**: Information relating to each research question was collected throughout the PhD as new literature, such as proposed electricity market designs, was published and additional stakeholder representatives were identified for interview. This fed into subsequent iterations developing responses to the research questions.

This iterative process allowed for the continued self-critique of the researcher's findings and ensured that the research is relevant to the current state of the debate, keeping up with the trends and state of knowledge which have emerged during the four-year program.

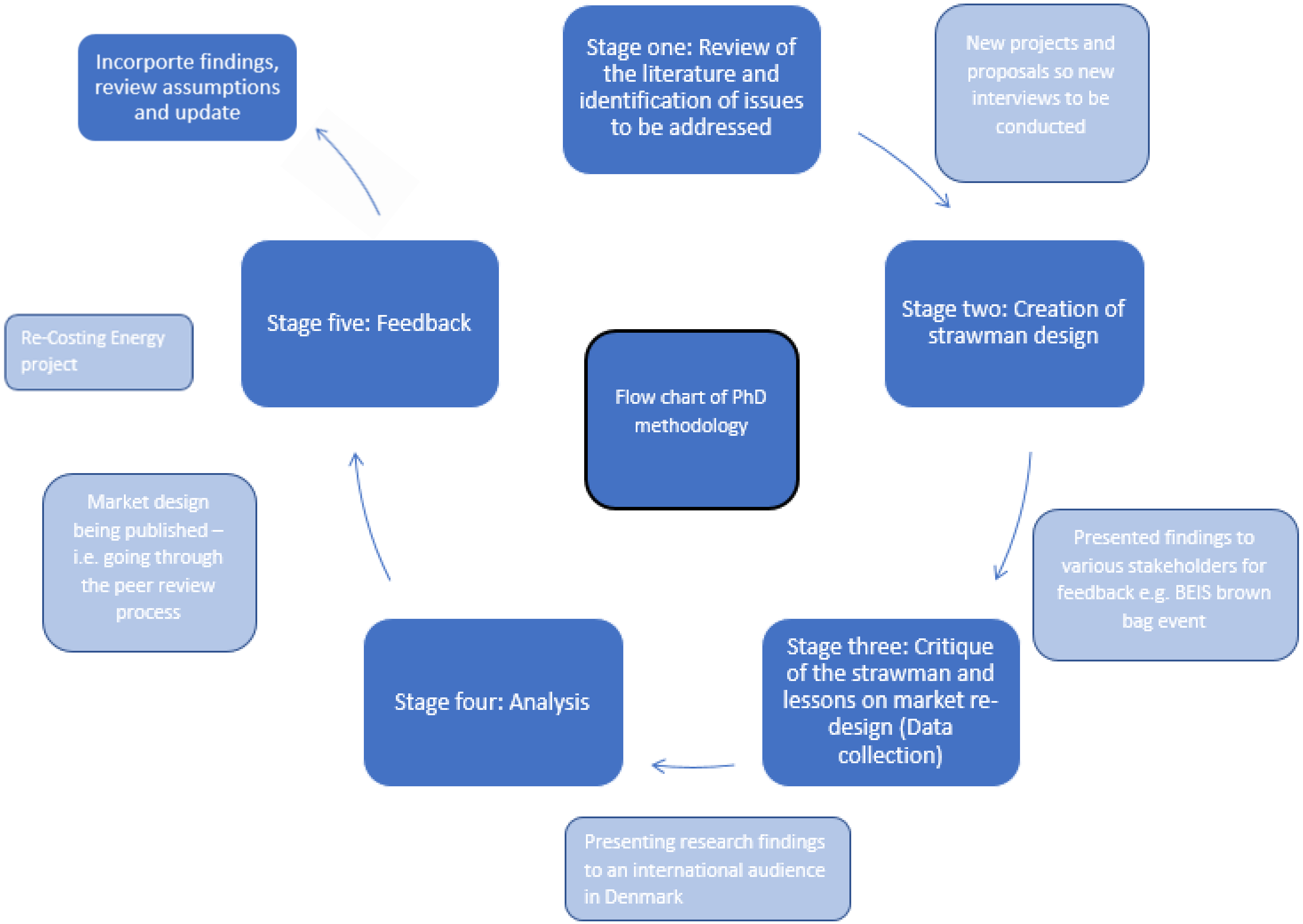

Figure 17 A flow chart of the PhD's methodology, illustrating the iterative nature of this research.

4.2 Literature review

An extensive review of the literature was conducted in order to situate this research within the broader academic and policy landscape of GB's electricity market design. According to Bryman (2016), reviewing the existing literature is critical to all research, as it is necessary to determine the current understanding of the topic as a precursor to generating any further knowledge.

GB's electricity market design is a highly regulated institution with both governmental (HM Government, Ofgem, BEIS) and non-governmental bodies (Elexon, National Grid ESO) producing a wealth of grey literature on electricity market design. For example, HM Government provides direction for the energy system which in turn sets the agenda for the electricity market design (Government 2017); Ofgem publishes on topics such as the liquidity of the wholesale markets offering insights into how electricity is traded (Ofgem 2016c); both BEIS and Elexon provide insights into how the electricity market actually operates (BEIS 2016b; Elexon 2017b) and National Grid ESO publishes on the current and future status of the balancing mechanism and the ancillary markets (National Grid ESO 2019a). Therefore, a review of the relevant literature from these regulatory bodies as well as other industry experts was carried out and the insights integrated into the knowledge basis for this research.

4.3 Conferences

The electricity system is undergoing rapid change meaning that much of the academic literature, and to some extent governmental publications, may be outdated soon after publication. There is therefore a need to ensure that the most up-to date information is sourced.

To demonstrate this a study by Björk and Solomon (2013) identified a time lag between research being submitted to an academic journal and actually being published. Their stratified random sampling technique identified 2,700 publications from 135 journals which revealed that under certain disciplines, including the social sciences and economics, it could take up to 18 months from the initial submission date to publication (Figure 18).

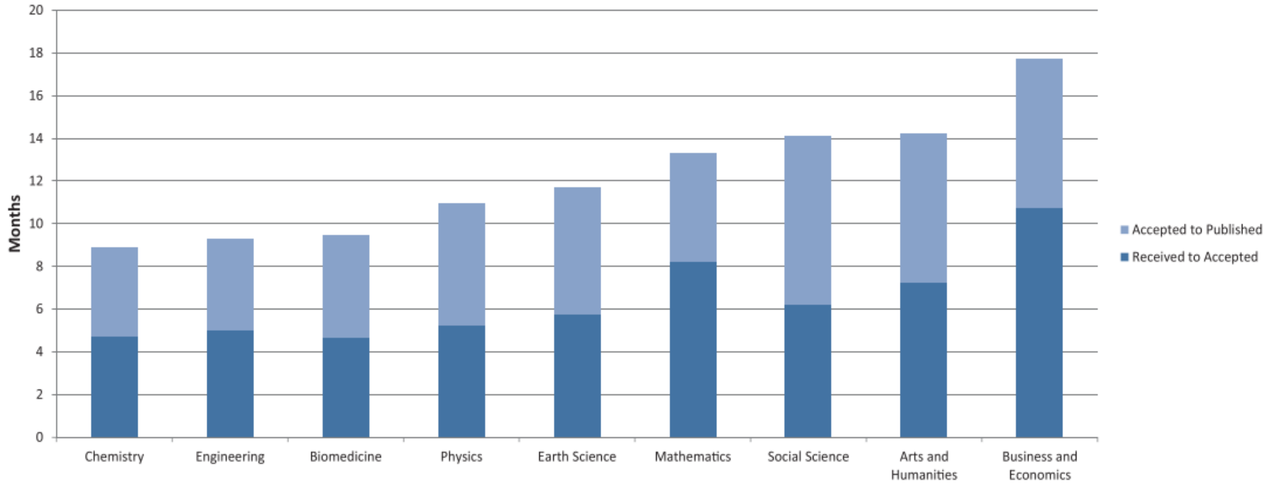

Figure 18 The average publication times in months by disciples. Source: (Björk and Solomon 2013).

In the rapidly evolving electricity system the role of journals should not be neglected, but the researcher must keep up-to-date with the latest developments in the field by, for instance, attending conferences which do not experience the same time lag (Oester et al. 2017).

Additionally, conferences provide an opportunity to meet industry experts. Research was conducted prior to an event: attendees useful to the development of this thesis were identified and then contacted to contribute to this research (Parsons 2015; Oester et al. 2017).

Once key experts had been contacted, a snowball sampling technique was employed to further identify individuals for this thesis. Snowball sampling is the technique in which the researcher contacts a relevant participant, and asks them whether they know anyone who may be of interest to this project (Fish and Busby 2005; Bryman 2016; Oester et al. 2017). This process is by no means random, and therefore people of a certain discipline are likely to be contacted. This is ideal for the study, as it is only those with prior knowledge of and expertise in electricity market design who will be able to provide valuable information (Bryman 2016).

4.4 Positionality of the researcher

No research is without inherent bias due to the epistemological, ontological, and axiological assumptions of the researcher (Bryman 2016). Therefore, it is essential to understand the positionality of those conducting the research as this will influence both the approach to data collection and the subsequent conclusions (Pring 2000; Geiger et al. 2012; Scotland 2012; Bryman 2016). As will be shown in chapter six, the researcher is proposing several augmentations to GB's electricity market design. The scale of proposed augmentations is, in the view of the researcher, justified by the scale issues with this institution. Yet, there may be other researchers who do not share this view.

Given the scope for creativity in market re-design, the thought processes and decisions leading to the eventual design proposed in this thesis must also be considered for possible biases. There are many different ways to design an electricity market, as can be evidenced by the various designs in operation around the globe today (Correljé and De Vries 2008; Gencer et al. 2020) and, as will be shown within chapter five, the high number of publications proposing alternative designs for GB. This leads to the question of whether another researcher would come to the same conclusions in terms of the fit for purpose electricity market design as this PhD thesis has.

These hypothetical designs presented in the literature provide a plethora of resources to build upon and inform the electricity market design for GB. Decisions about whether proposed alternative modules should be incorporated or omitted from the strawperson design were taken by the researcher on the basis of the goals of the proposed electricity market design as stated in section 4.5.2.1. Using the same methodology as employed here it is expected that other researchers' proposed design would differ based on their particular goals, as is the case with existing proposals from, for example IEA's design (2016).

Going forwards, the electricity system will undergo continued change as the goals of the system will evolve too, this will imply different requirements of the electricity market design, as has happened in GB in the past (Kern et al. 2014). In particular, the increased participation of VRE will modify goals in relation to the procurement of flexibility and system security. In response, new functions of the electricity market design in question will be required and for that reason it is expected that future electricity market designs will differ from that being proposed here, even if the researcher follows the same methodological steps that are in place here.

4.5 Addressing the research questions

4.5.1 In what ways is the electricity market design in Great Britain no longer fit for purpose?

Addressing this research question required a review of the issues with the current institution as to date there is no single bank of information of the range of issues facing the electricity market design within GB. A deductive approach was employed through an extensive literature review, reviewing governmental, academic and industrial literature which was built upon by the attendance of conferences, semi-structured interviews and the participation in external projects such as ReCosting. This led to the compiling of a detailed list of issues facing this institution.

4.5.2 What does a fit for purpose electricity market design for Great Britain look like?

Prior to conducting the semi-structured interviews, the proposed strawperson electricity market design for GB was created with clear justification and evidence for each element of the proposed design.

Creating a design to be discursively critiqued in order to further one's data collection is not a new technique within the literature. Discussing the utility of studying design concepts for mechanisms for resource allocation, Hurwicz (1973: 27) stated that:

> "The new mechanisms are somewhat like synthetic chemicals: even if not usable for practical purposes, they can be studied in a pure form and so contribute to our understanding of the difficulties and potentialities of design. The design point of view enlarges our field of vision."

Recently, an alternative electricity market design created by Peng and Poudineh (2017) used this same approach to facilitate the discussion with stakeholders on their proposal, whilst both Market4Res (2016) and European Commission (2019) used this approach to identify merits and issues of their proposed alternatives as well, highlighting the practical applicability of this method.

4.5.2.1 Goals of the proposed electricity market design for Great Britain

As explained in chapter two, the emphasis on the efficient delivery of secure, reliable electricity at competitive pricing in the objectives of GB's electricity market design can be understood in the context of market liberalisation. However, the achievement of a net zero electricity system within GB requires the reconsideration of the market design with implications for how these objectives are realised (Nelson et al. 2017; De Vries and Verzijlbergh 2018; Cornwall Insight 2020a).

These four objectives could be facilitated in a variety of different, often mutually exclusive, approaches. For example, some may argue that all four of these objectives could in theory be satisfied primarily through the deployment of nuclear generation; whilst others dismiss such a centralised scenario in favour of an increasingly flexible, decentralised electricity system which encourages the participation of the demand side. Therefore, intended goals of the proposed electricity market design for GB have also been cited from the literature to guide the proposed design:

- **Goal one**: As renewables are foreseen to become the dominant player within the markets in light of net zero, the market design should be designed around their characteristics (Bauknecht et al. 2013; European Commision 2016; Cramton 2017; Peng and Poudineh 2017; Roques and Finon 2017).
- **Goal one-b**: Promote services required in an increased variable grid - i.e. flexibility (Bauknecht et al. 2013; Riesz et al. 2013; Ilieva et al. 2015; IEA 2016; Roques and Finon 2017; ENTSOE 2019).
- **Goal two**: Promote market conditions which provide investment signals and dispatch for flexible technologies and services (Kustova and Egenhofer 2019; Ofgem 2019b; Energy Systems Catapult 2021).
- **Goal three**: Promote the revealing of regional geographies (Roques and Finon 2017; ENTSOE 2019).
- **Goal four**: Open markets up to all technologies and services, regardless of their size or location on the network (Ilieva et al. 2015, 2016; IEA 2016; Lund et al. 2016; Peng and Poudineh 2017; Ofgem 2019b; Sorknæs et al. 2020).

- **Goal five**: Promote a liquid, competitive set of markets (ACER 2015; IEA 2016; Mitchell et al. 2016; Bielen et al. 2017; Gimon 2017; Peng and Poudineh 2017; ENTSOE 2019).

These goals help identify concerns with the current market design alongside providing insights into how the current electricity market design would need to be augmented in order to facilitate these goals and objectives. Any concerns with the design itself could be amended through the iterative process in order to create the fit-for purpose electricity market design which would achieve the intended goals.

The next sub-section will explain the approach used to create the electricity market design for GB; a process known as modularisation.

4.5.2.2 What is modularisation?

The methodology applied to generate the proposed market design for GB was devised with reference to the approach taken in previous studies developing electricity market design concepts. Few studies set out their methodology, but three which did have all employed the technique of 'modularisation' (Franco et al. 2015; Peng and Poudineh 2017; Roques and Finon 2017). This sub-section explores this process, how it has been applied previously, and the merits of such an approach for the purposes of this thesis.

In essence, modularisation is the process of taking a system and breaking it down into its interrelated units or 'modules'. It is a form of design structure in which the independent modules and their associated links and tasks are analysed across the system in order to identify issues or problems and suggest solutions with the intention of improving the efficacy of the design (Baldwin and Clark 2000).

The foundations of modularisation are drawn from design theory, pioneered by Christopher Alexander's seminal urban planning research in which he contends that a system can be thought of as a hierarchy of nested sets (Alexander 1965). These sets and sub-sets are later referred to as modules in the work of Baldwin and Clark (2000).

Baldwin and Clark's (2000) seminal work used the example of partitioning a business hierarchy into its constituent sectors, or modules, in order to understand the links between them. They used this approach to analyse whether these modules and the links between them were an efficient means of structuring the business in relation to the business's goals. In doing so they were able to identify which modules could be re-configured, and how links between these could be improved in order for the system as a whole to become more efficient (Baldwin and Clark 2000).

Baldwin and Clark highlight how the concept of modularisation incorporates several principles from design theory which provide the means for one to divide up the knowledge and specific tasks that are part of completing a complex design (Baldwin and Clark 2000). These include the importance of design rules, how tasks can be split into independent blocks, and how there are interactions between these blocks (Baldwin and Clark 2000).

4.5.2.3 What are modules in the context of this thesis?

Since Baldwin and Clark (2000), modularisation has been applied across a wide variety of scholarly research including, for example, the systemic impacts of technological evolution (Arthur 2009), the governance of global value chains (Gereffi et al. 2006), and the biological robustness of system functions in relation to internal or external perturbations (Kitano 2004).

Modularisation has also been applied to different elements of the electricity sector, such as Glachant and Perez's (2009) work identifying the value chains within the power sector, and more recently to electricity market design, notably in the work of Franco et al. (2015), Peng and Poudineh (2017) and Roques and Finnon (2017).

Franco et al. (2015) use the modular approach to represent information flows between the different modules at the time of the EMR in GB. Through incorporating this approach the authors analyse the long-term effects of the EMR in GB to argue from their stance that this market design intervention was required to achieve the policy objective of delivering security of energy supply at an affordable price (Franco et al. 2015). Figure 19 illustrates the authors' visualisation of the EMR in its constituent modules and the information flows identified between them.

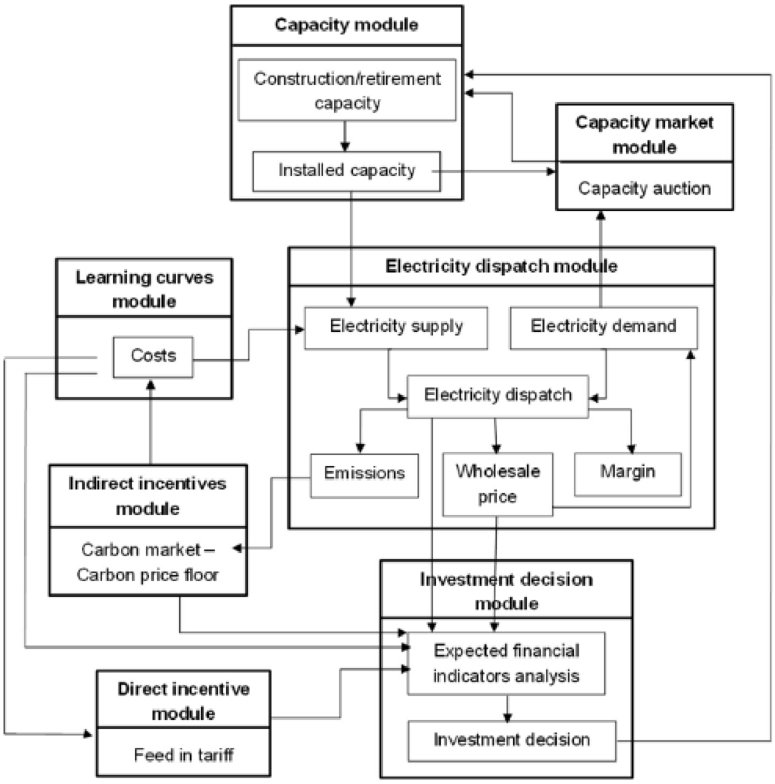

Figure 19 A modular representation of the dynamics of the EMR policies within GB's electricity market. Source: (Franco et al. 2015).

In the second example, Peng and Poudineh (2017) used modularisation to demonstrate that the characteristics of the existing wholesale market modules are misaligned with the integration of renewable generation i.e. through introducing support schemes for VRE. It is these misalignments which have led to unintended consequences such as the dampening of the wholesale price of electricity (as will be discussed in chapter five).

In order to demonstrate the coordination between the existing modules and the incorporation of new VRE support modules they display elements of the power sector as separate modules with links between them (Figure 20).

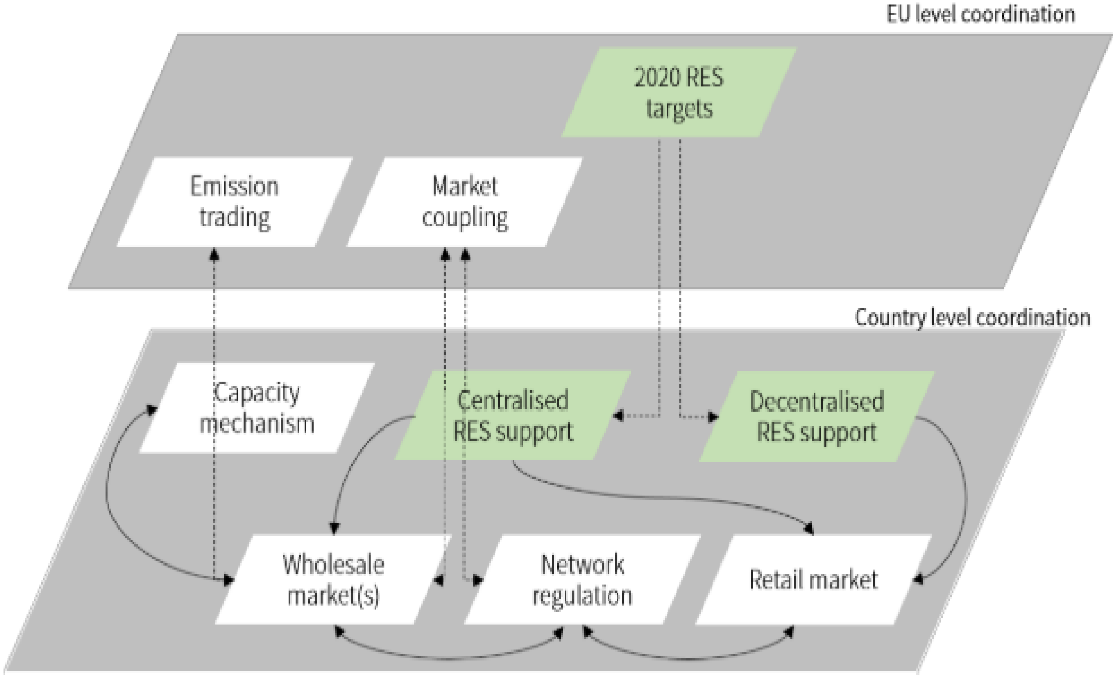

Figure 20 A modular representation of the EU power sector with coordiatnion mechanisms. Source: (Peng and Poudineh 2017).

This approach allowed the authors to identify and explore misalignment between modules, the issues that have emerged as an outcome of these misalignments between new and existing modules and, in their opinion, how best to reconfigure these modules to achieve system objectives (Peng and Poudineh 2017).

Similarly, in the work of Roques and Finnon (2017), they incorporated modularisation to review the current electricity market design in GB to identify misalignment between modules. Through this approach they identified how misalignments could be addressed through reconfiguring the electricity market to incorporate long-term modules to support renewable generation (Figure 21) (Roques and Finon 2017).

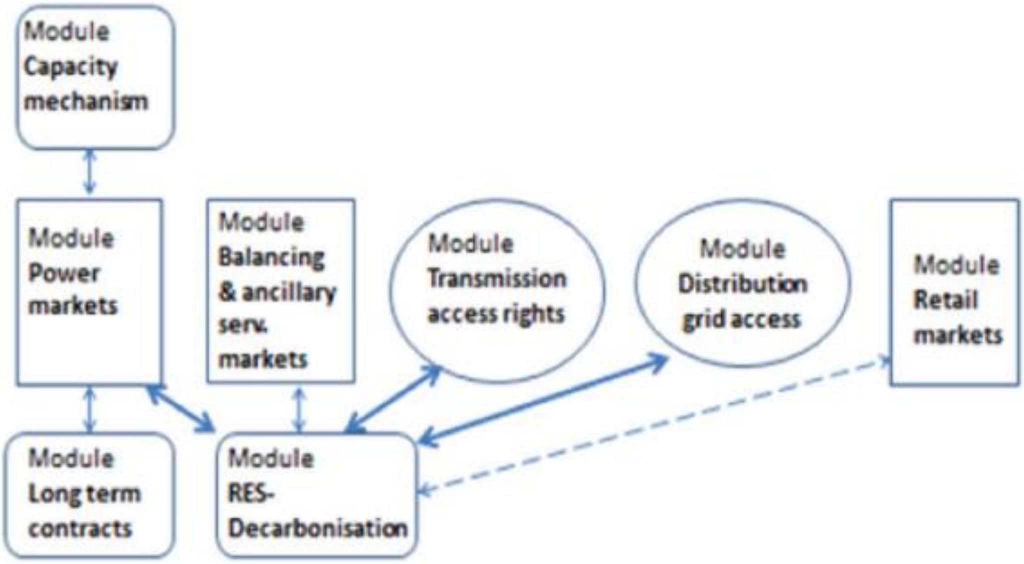

Figure 21 A modular representation of the initial modules and the three additional long-term modules. Source: (Roques and Finon 2017).

In summary, the previous examples illustrate seven advantages of using modularisation to analyse and suggest improvements to the electricity market design (Baldwin and Clark 2000; Franco et al. 2015; Peng and Poudineh 2017; Roques and Finon 2017):

1. Modularisation has been successfully applied in studies exploring electricity market design in order to identify issues and how they may be rectified through the reconfiguration of modules within the electricity market design.
2. The flexibility of modularity to fit the scope of the research. Each example focuses on a different area of the market design. This highlights how the interpretation of modules within the structure of the electricity market design depends on the study and the specific research question. This approach has the possibility to be applied to a range of projects related to the re-configuration of an electricity market design and can therefore contribute to the answering of research questions.
3. GB's electricity market design is an inherently modularised system constructed of modules and the links between them.
4. Issues with GB's current market design can be identified and potentially rectified through the reconfiguration of these modules.
5. The researcher can visualise and analyse the relationship between different modules.

6. A complex system can be broken down into discrete, manageable modules, as opposed to addressing a complex system as a whole.
7. There is also a benefit in focusing on multiple modules concurrently, allowing the researcher to re-configure these modules at the same time. In doing so, these modules evolve together, following the same path, rather than being addressed separately which could lead to divergence and misalignment.

These three studies which have employed a modularisation approach have each identified the modules of interest to their research within the electricity market design; these modules have been mapped onto the various electricity ‘marketplaces’. Chapter two, 2.2.1 introduced the different marketplaces which constitute the electricity market design within GB. These were:

- The wholesale market
- The balancing mechanism
- The ancillary market
- The capacity market
- Local electricity markets
- Low carbon subsidies

Following previous studies, each of the markets plus low carbon subsidies are considered ‘modules’ in this thesis i.e. the wholesale market is a module.

4.5.2.4 Why use a strawperson design?

A strawperson design is a draft concept which intends to solve a specific issue. As a concept, a strawperson design offers a focal point for discussion and provides the stakeholders involved with a basis on which to discuss the efficacy of the design and propose how it can be improved. This approach is often cited by consultancy firms such as McKinsey (2013) and tech firms (Technopedia 2011) which see the presentation of a strawperson design as a means to initialise discussions and gather feedback on a proposal iteratively and improve the base concept.

4.5.2.5 The process of creating the strawperson design

This section will introduce the steps involved with the creation of the strawperson design.

1. **Identifying the modules to be included**: Following the methodologies set out in the three papers explored in section 4.5.22, the modules within the GB electricity market design and the links between them were identified.
2. **Reconfiguring the existing modules**: Existing modules underwent a process of reconfiguration. Alternative arrangements for each module were identified drawing upon concepts from the 49 papers with proposals for electricity market reform reviewed and summarised in chapter five, section 5.3 and in appendix three. The decision on how to reform each module was made by the researcher, based on the perceived efficacy of each design to facilitate the objectives and goals of the electricity market and for which there was evidence of support or agreement in the literature. Agreement stemmed from either the particular source (e.g. an academic publication) being heavily cited or the proposed element being repeatedly proposed across numerous sources (e.g. the need for a market for flexibility).
3. **Identifying if there are any 'missing modules':** The process of identifying and specifying existing modules served to highlight missing capabilities or modules, e.g. a market for a specific service or a market required at the distribution level. Combined with step two, this provided an overview of all market modules and any missing modules. For example, one of the goals of the proposed electricity market design was the incorporation of decentralised assets which have limited access to value under the current electricity market design. As such, a new module was created to achieve this goal based upon proposals identified within the literature. However, as evidenced by Baldwin and Clark (2000), a new module needs to fit in with the wider institutional framework to avoid misalignment and subsequent issues which would arise from this. Therefore, care was taken to ensure alignment either because this new decentralised module would fit into the existing institutional framework or, where necessary, through specifying a reconfiguration of the existing framework to harmonise all modules within this design.

4. **Piloting of the strawperson design:** Stages one through three led to the creation of the initial strawperson design. This design was then piloted via two semi-structured interviews and a roundtable event to identify any initial concerns which could be addressed before starting the interview process.

This process led to the creation of the strawperson design which was then proposed and validated as will be explained in section 4.6.3.

4.5.2.6 Modularisation and institutional change

The process of reconfiguration was influenced by the modularisation and HI literature. The scholarship on modularisation proposes two applicable forms of reconfiguration (Baldwin and Clark 2000):

1) Augmentation: Introducing a new module which embodies new concepts to an existing modular system, addressing a specific need not currently catered for.
2) Exclusion: Removing a module which is no longer required.

However, as evidenced in chapter three, section 3.1, the process of electricity market re-design cannot be fully accounted for within the frames of augmentation and exclusion; there needs to be a means to reflect the incremental change observed in actual market development such as through the introduction of additional balancing services products.

Drawing upon the HI literature, this thesis argues that the incremental process of change can be captured using the concept of layering (as introduced in chapter three). This process of change refers to new rules being attached to an existing institution, or module in this case, to provide an additional function (Mahoney and Thelen 2010a). This differs from augmentation which implies the introduction of a new module; instead, the function of an existing institution is modified to serve an additional purpose. This can be evidenced by the reconfigurations of current modules within GB's electricity market design, such as the introduction of DC, a new product within the balancing mechanism, which procures a new service within the same broad structure of the balancing mechanism (National Grid ESO 2019a).

4.5.3 What recommendations to policymakers can be identified to aid the process of contemporary electricity market re-design?

An additional literature review was conducted into the publications from governmental and non-governmental organisations authored by those with the agency to enact the process of electricity market re-design. This included literature from the European Commission, BEIS, Ofgem, the ENA and National Grid ESO. Furthermore, during the semi-structured interviews, questions were asked to the interviewees on the process of implementing the proposed electricity market design for GB. This was centred around the themes of drivers to implementation, the barriers and proposed solutions to overcome these. This provided the basis for understanding the lessons to aid policymakers within this process of institutional change.

4.6 Data collection: Interviews

The primary means of collecting data was through conducting semi-structured interviews. This section details the inductive process employed.

4.6.1 Identifying participants

Participants were identified for recruitment into the study programme in a number of ways. Desk research identified prominent academics, governmental and non-governmental representatives, professionals employed by energy suppliers and other bodies with expertise in how the electricity market operates and who had views on whether and how GB's market design needed to evolve. Attendance at conferences and training workshops provided direct access to more professionals in the field. In addition, snowball sampling facilitated connections to other relevant experts (Bryman 2012).

4.6.2 Piloting

Having created a strawperson electricity market design for GB and identified interview participants, the interview process was piloted. The pilot study provided vital information about the realistic timeframe for the research, the relevance of the questions, the feasibility of the intended approach, and the usefulness of the data collected (Fish and Busby 2005; Nelson and Alfred 2005; Alshenqeeti 2014; Evens et al. 2014; Bryman 2016).

Two pilot interviews and one roundtable event were organised in order to ensure that:

1) The proposed straw electricity market design did not have any critical flaws which would take up valuable time during future interviews,
2) The questions asked led to useful data being collected,
3) The timings of each section of the interview were of a length appropriate to allow the required depth to be achieved,
4) The interviewer would bring the correct resources for discussion.

The outcome of piloting led to certain amendments e.g. originally a table of all the proposed electricity market designs which had been reviewed were presented to the interviewee (appendix three). This was found to be too much information for the interviewee to digest and therefore this resource was removed from the interview process. However, as this was useful information for framing the scale of changes being proposed a link to a blog which showed the same information was instead provided prior to the interview taking place to provide the interviewee with the necessary background knowledge (Pownall 2019).

The piloting resulted in a smoother interview process and enhanced data collection.

4.6.3 Validation and appraisal of the strawperson design: Semi-structured interviews with market design experts, conference presentations and academic publication

The strawperson design was appraised by industry experts via 41 semi-structured interviews with a range of stakeholders from both GB and Denmark (appendix four).

These experts were selected based upon their involvement within the electricity market. For example, academics who had published on the electricity market design, consultants who had authored working papers on this topic, and energy suppliers who were actively involved within the markets. Interviews centred on discussion of the proposed design and provided opportunities for interviewees to identify aspects of the design requiring further alteration. Follow-up interviews were carried out to explore subsequent alterations to the proposed strawperson design.

Furthermore, respondent validation was employed to ensure that the views of the interviewees collected were accurate (Bryman 2016). Interviews were recorded and verbatim transcripts were provided to the interviewee before any element was incorporated. This process allowed each interviewee the opportunity to provide feedback on the transcript, ensuring their views were accurately captured with amendments made where necessary.

The proposed electricity market design was also appraised when presented at various national and international conferences and when it was submitted to a special issue in the journal Energies in which it was scrutinised via the peer-reviewed before publication (Pownall et al. 2021).

This provided a breadth of views and improvements on the proposed electricity market design detailed in the following section, including the feasibility of the proposed design alongside how the proposal, in their expert view, would perform against the objectives.

4.6.4 Why semi-structured interviews?

The interviews were conducted using a semi-structured method in order to allow the exploration of complex topics, whilst understanding the justification and contextual factors which formed the participant's opinion (Keats 2000; Legard et al. 2003; Bryman 2016).

Additionally, semi-structured interviews are flexible by nature, and therefore allow for unforeseen, yet relevant topics to be delved into. This provides a more holistic examination which is important given that the literature may not explore all aspect of GB's electricity market design (Keats 2000; Legard et al. 2003; Bryman 2016).

The use of unstructured interviews was considered but ultimately not adopted as it was likely to result in discussions with too little consistency or direction to ensure key areas of interest were covered.

These interviews were carried out face-to-face whenever possible, and otherwise through other mediums such as Skype or over the phone. It has been argued that face-to-face interviews are the ideal technique as higher retention of participant engagement and stronger rapport due to non-linguistic cues result in more information being obtained, compared to online or phone interviews (Frey 2004; Gray 2014; Bryman 2016). However, telephone and skype interviews offer benefits such as relative ease as well as the reduced expense and time requirement of calling someone, rather than travelling to them (Bryman 2016).

4.6.5 Prior to the interview

Once the participant had agreed to an interview a research brief and consent form were sent, in compliance with the University of Exeter's policy.

The research brief explained the context of the study, the role and use of interviews as data collection, the possible outputs from this research and the ethical considerations (available in appendix five). Within this brief the themes to be explored through the research were clearly conveyed as a means to set a boundary around the topics of the discussion. Sending this information in advance allowed the participant time to think about his/her answers beforehand so they could provide more depth, compared to the question being a surprise. This fits into the semi-structured nature of the interviews and themes emerging over the course of the interview were pursued where the researcher thought there would be merit in their exploration.

The consent form also asked whether participants would be comfortable with a Dictaphone being used to allow a verbatim transcript to be created. In one instance the participant wished to turn off the Dictaphone for the whole interview to facilitate an off-the record conversation which they believed would allow for them to give their honest opinions given their employment status. In this case, notes were still taken, and the themes were then sent to the participant in this particular case to be verified.

4.6.6 During the interview

Interviews were designed to last one hour as a means to keep the conversation concise. The interview questions were principally open-ended as a means to allow the participant to express their views without being confined by the question posed by the interviewer (Bryman 2016). Following a consistent order for the questions provided a logical flow to the discussion and allowed for a range of themes to be explored.

The first question posed to the interviewee was designed to be an easy, open-ended question as a means to create a relaxed atmosphere for the participant. This is argued to result in richer responses to follow up questions (Mason 2002). For example, if their job role is related to the process of electricity market re-design, a common opening question was ‘What is your role within your company?’.

The questions asked were split into three themes:

Theme 1: The future of the electricity system in your view

Theme 2: The need (or not) for implementing a new electricity market design

Theme 3: My proposal

More detail on the questions asked can be found within Appendix five.

The use of a Dictaphone meant that the researcher would not have to focus on taking verbatim transcripts during the interview as the recording software would provide this. This freed the researcher to focus on the key themes that emerged during the interview and minimised the chance of these themes being missed as a result of the interviewer being distracted by transcribing throughout the interview. An additional benefit of this is that the interviewer could actively listen to the respondent’s views encouraging a two-way flow in the conversation.

4.6.7 After the interview

Interviews were transcribed and sent to the respective participant shortly after the interview took place. It was made clear during the interview that these transcripts would not be incorporated into the thesis until the respondent had had the opportunity to review the discussion and approve the transcript. In practice, only a few made edits to their transcript.

By writing up the transcripts, additional themes emerged. As the transcript was to be emailed to the participant, further questions could also be asked within the same email. Communicating with the participant helped to maintain a good working relationship with the interviewees which allowed for easier facilitation of follow up meetings if required.

Through sending the transcript to the participant and allowing the respondents to confirm that the views represented during the discussion came across as intended increased the robustness of the transcripts.

The transcripts were also reviewed by the researcher to ensure that the researcher was conducting themselves appropriately (e.g. not asking leading questions) and helped identify areas which could be explained better in subsequent interviews.

4.7 Data collection: insights from Denmark

The focus of this thesis is on the GB electricity market design, but an international case study can provide additional learning to better inform responses to the research questions. A single case study may offer insights into a particular area, but there are transferable lessons that can be gathered through the incorporation of an additional study (Flyvbjerg 2006).

The incorporation of a secondary case study, Yin (2014) suggests, will provide a wider contextual understanding of the factors at play. The use of multiple case studies has also been suggested to further provide robust evidence as it allows the researcher to make a cross comparison between two, or more, different experiences (Yin 2014).

Interviewees from Denmark were selected for two main reasons. First, they had carried out pioneering research on the smart energy system (SES) approach[1] (Lund et al. 2016; Sorknæs et al. 2020) which provided useful insights applicable to the proposed market design in chapter six. Second, Denmark is considered a 'world leader' in the transition towards an economy underpinned by VRE (Sovacool 2013; Lockwood 2015), and the interviewees' professional experience of this energy transition provided highly relevant lessons for the requirements of a future electricity market design, the incorporation of which into the proposed design are valuable.

The collection of data from Denmark was carried out in two phases.

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[1] A concept which will be explored in chapter five, section 5.1.7.

The aim of the first phase was the collection of initial insights from key market experts from both the University of Aalborg and the Danish Technical University. These institutions were selected due to their breadth of publications in the field of electricity market design (See, for example: (Kitzing et al. 2012; Doganova and Karnøe 2015; Sorknæs et al. 2015; Djørup et al. 2018)). During time spent at both universities the researcher presented the findings to date on research questions two and three. The researcher also presented at the University of Aalborg's IREMB conference in which further thoughts on the proposed electricity market design for GB and how the market evolves were collected (IREMB 2019).

The insights gained from phase one were incorporated into the proposed electricity market design whilst also furthering the researcher's thinking on the pressures which led their market design to evolve. The second phase planned a revisited to the two previous institutions as well as governmental and non-governmental bodies with the purpose of conducting semi-structured interviews with market design experts. Many of these contacts had been established during the first phase.

However, the two countries operate different electricity market designs. For example, GB operates under a national pricing system with a single price for electricity, whereas there are two pricing zones in Denmark, with the price of electricity differing dependent upon congestion between these zones (See appendix six, section one for more details on these differences). Whilst these differences limit the scope for a direct comparison between the current two market designs, the ability to accommodate regional price differentiation is an element this thesis seeks to integrate to the proposed electricity market design introduced in chapter six. The interviewees with expertise in the Danish system therefore brought directly relevant additional knowledge to the research in terms of how to engineer the market design in order to accommodate regionally differentiated price information.

It must be noted that the second phase coincided with the outbreak of Covid-19 and the subsequent restrictions on movement and social contact which were introduced. As a result, the second phase was limited in terms of interviewees as there was not the scope to travel to Denmark and repeated attempts to contact relevant stakeholders via email yielded a low rate of response.

4.8 Data collection: Re-Costing Energy

In addition to the aforementioned methodology the researcher was also able to collect relevant data through involvement in an external project. The researcher was actively involved with the Re-Costing of energy project run by Laura Sandys. This project focused on how the energy system, including the market structures, requires reconfiguration in order for GB to reach a net zero electricity sector in the UK (Sandys and Pownall 2020). This project therefore shared objectives with the questions addressed in this thesis and provided an additional means of collecting data.

Involvement in this project allowed the researcher to attend several meetings with key industry bodies such as BEIS, Ofgem, National Grid ESO, think tanks, energy suppliers, and investment bodies. During these discussions the researcher took detailed notes detailing the views and themes of these representatives on many topics related to the PhD research questions themselves. These discussions provided another means to validate the assumptions made within this thesis. For example, discussions with stakeholders which focused on the efficacy of GB's current electricity market design often led to the narrative of a missing module at the local level on the network. This in turn provided further assurances on the need to introduce a new module into the proposed market design within this thesis.

4.9 Data analysis

Transcripts were coded with the assistance of the software package NVivo, this tool was selected due to its prominent usage in social science research and its ability to identify and explore key themes within transcripts (Butler et al. 2013; Chmutina et al. 2014; Goulden et al. 2014). Coding involves the identification of ideas within the data which can then be organised into themes. Themes can then be analysed and explored in order to address the research questions. Themes can be defined as patterns within the responses which provide meaning from the data, and will emerge as the interviews are transcribed (Harper and Thompson 2011).

The codes were primarily based upon the tenets of the theoretical framework, identifying thematic analysis which has been argued to increase the robustness of the research by ensuring the research findings are theory driven (Sacred Heart University

2006; Grant and Osanloo 2014; Stewart and Klein 2016). For example, themes based upon the tenets of HI such as themes of ‘resistance’ were initially set up as codes. Codes were also based on the questions being asked of interview participants. These were themed in three ways ‘market participants’ thoughts on the current electricity market design, ‘thoughts on the proposed electricity market design’ and ‘considerations on how to transition’ which reflect the three research questions. Codes also emerged naturally from the transcripts which were then incorporated into the NVivo codebook. Codes were re-examined on multiple occasions to assess whether a particular node would be better suited and an alternative node, or whether a new node was required.

The use of NVivo allowed for a flexible approach to compiling the themes within this research. An initial set of themes were anticipated and throughout the process of data collection and analysis new themes which emerged were incorporated into the NVivo analysis in an iterative fashion (Hoover and Koerber 2011).

The codes were interpreted on an individual basis and then compared against one another in order to further explore the themes which were emerging. In addition to this, there were quotes which represent these themes and these are incorporated into the results section. In compiling the relevant themes from interviewee responses in NVivo, it allows for comparisons to be made, such as which groupings of interview participants were for, or against, features of the proposed electricity market design (Hoover and Koerber 2011).

4.10 Research approach: Limitations and solutions

In all interview based studies, there is scope for the researcher’s personal views and bias to come through and influence the results (Russell Bernard 2011). The solution to this is that the researcher should be mindful of such bias and ensure an open space for respondents to give their honest views (Strauss and Corbin 1998). In this case, researcher bias was mitigated in the interview structure through the use of open-ended questions and reflecting on pilot interviews to ensure that the interview technique was not in any way leading.

In order to validate the research findings and further ensure that there was no researcher bias, ‘respondent validation’ was employed (Bryman 2016). The researcher employed three techniques to validate themes collected. First, during the interview once an interviewee has expressed a relevant view the interviewer would summarise the key points made to allow the interviewee to confirm this is correct or explain their comments further. Second, all transcripts were sent to the interviewee to read through which allowed them to make any amendments and clarifications. Third, an interpretation of the key themes which emerged was sent to several participants to make sure that the transcripts have been interpreted as the participant intended them to be.

4.11 Ethical considerations

The methods used in this thesis including the interview design were approved through the University of Exeter’s research ethics process. In addition, all transcripts were kept in two separate locations: One on the laptop, which would require two passwords to access the folder of the transcripts and then a further custom password for each transcript, and the other was kept in a locked filling cabinet.

4.12 Chapter conclusions

This chapter detailed the methodology undertaken within this study, alongside acknowledging the positionality of the researcher. Subsequent chapters introduce the findings stemming from undertaking the steps outlined within this chapter.

5.0 Issues with Great Britain's electricity market design, alternative proposals and the scale of alterations required

Chapter five employs the methodology detailed in chapter four to address RQ1 'In what ways is the electricity market design in Great Britain no longer fit for purpose?' by providing a detailed account of why the current institutional set-up is not 'fit for purpose'. This will provide the rationale for a new electricity market design (RQ2) which will be introduced in the following chapter.

In addition, this chapter will review the proposed alternative market designs identified in the literature and present analysis from this review. The number of publications from both academic and industry proposing alternative market design arrangements has increased over recent years and reasons for this are discussed. The degree of change proposed in alternative designs is also explored, observing that whilst there is a consensus that market re-design is required, there is no common view on the scale of change required.

5.1 Issues identified within the literature

This section will detail the issues with GB's electricity market design which primarily stem from a divergence between this institution and the rapidly transforming characteristics of GB's electricity system; as this institution has predominantly undergone a series of only minor alterations which have been inadequate. The result is an outdated electricity market design which has a number of functional problems.

5.1.1 Missing money

The dispatch of generating assets is price-based which, in turn, is determined by plants' Operational Expenditure (OPEX), principally fuel costs (BEIS 2020e). The more efficient thermal assets entering the market with lower OPEX will outcompete older units which are therefore not signalled to dispatch as frequently, as illustrated in Figure 22. Variable renewable generating assets have no fuel costs and therefore near-zero OPEX which exacerbates this phenomenon, displacing further conventional generating units[1] (Riesz and Milligan 2015; Keay and Robinson 2017; Peng and Poudineh 2019). The removal of the more expensive units lowers the market price and results in a lower capture rate for those still required to meet demand. This reduces returns and therefore the incentive to invest in technologies and services which will be reliant upon this clearing price as a revenue stream. Ultimately, this is leading to concerns that generation capacity may be inadequate in the long-term (Hogan 2005a; Bauknecht et al. 2013; Roques and Finon 2017). This problem has become known as the 'missing money' phenomenon (Hogan 2005a; Bauknecht et al. 2013; Roques and Finon 2017). This can have serious implications on GB's long-term security of supply if future investments into the required service providers are not forthcoming due to inadequate investment signals stemming, in part, from the missing money phenomenon.

The extent of this phenomenon will be case dependent. If the clearing price is routinely set by a certain OPEX generator then the profits of all the cheaper units will be dependent upon the aforementioned being dispatched. Therefore, if displaced, the influence of missing money phenomenon will be greater. Conversely, displacing an expensive unit which is rarely dispatched will have a limited impact on the clearing price as this unit does not routinely set the clearing price.

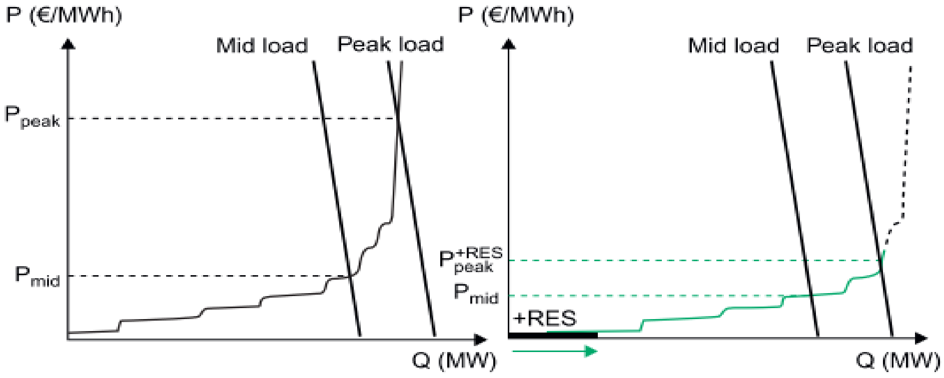

Figure 22 Illustration of price suppression due to an increasing level of VRE on the system. As renewable generation meets the initial demand, it brings forward the mid and peak load, pushing out the more expensive generators as indicated by the dotted line on the right hand chart. Either form of clearing electricity, be that Pool or bilateral, will be impacted the be depressing nature of VRE uptake. Though this occurs in both bilateral and Pool markets, due to the opaque nature of bilateral trades this is not as clearly illustrated as with trades clearing within an exchange with the cleared prices publicly known. Source: (Bauknecht et al. 2013).

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[1] BEIS's generating costs (BEIS 2016c, 2020e), estimate that a CCGT H Class commissioned in 2025 would have an OPEX cost of £76/MWh, a fee consisting of the operation and maintenance, which is applicable to onshore wind, but also a fuel and carbon costs which are not applicable to onshore wind.

5.1.2 Price cannibalisation and the rise of negative pricing

The ‘missing money’ phenomenon is exacerbated by the presence of high levels of VRE output which can lead to ‘price cannibalisation’ (Cornwall Insight 2018c; López Prol et al. 2020). For instance, if total demand is satisfied by VRE then they, rather than a thermal asset, will set the clearing price; problematically, based upon their near-zero marginal costs, the clearing price could drop as low as £0/MWh (Cornwall Insight 2018c). This is a very low the capture rate for VRE technologies who, in spite of bidding in low to the market, rely on revenue modelling which assumes prices above zero. The risk is especially high for those operating in the market without a form of revenue assurance scheme such as a CfD, potentially increasing the reliance on these support mechanisms in the future as a means to secure investment (Keay and Robinson 2017; Cornwall Insight 2018c). In fact, as 5.1.2.1 will explain, this phenomenon is exacerbated further still by these very support mechanisms, namely the ROC and CfD.

Recipients of the CfD and the RO are financially incentivised to generate as much as possible as their subsidies pay out based on their generating output. Recipients can therefore theoretically bid low, if not negative prices, to increase the chance that they are dispatched even when the price is low, on the basis that the subsidy will pay them anyway. Cornwall Insight analysis reported that the theoretical minimum bid that subsidy recipients can offer and still break even is around -£170/MWh, knowing that they would be paid based on their CfD (Figure 23).

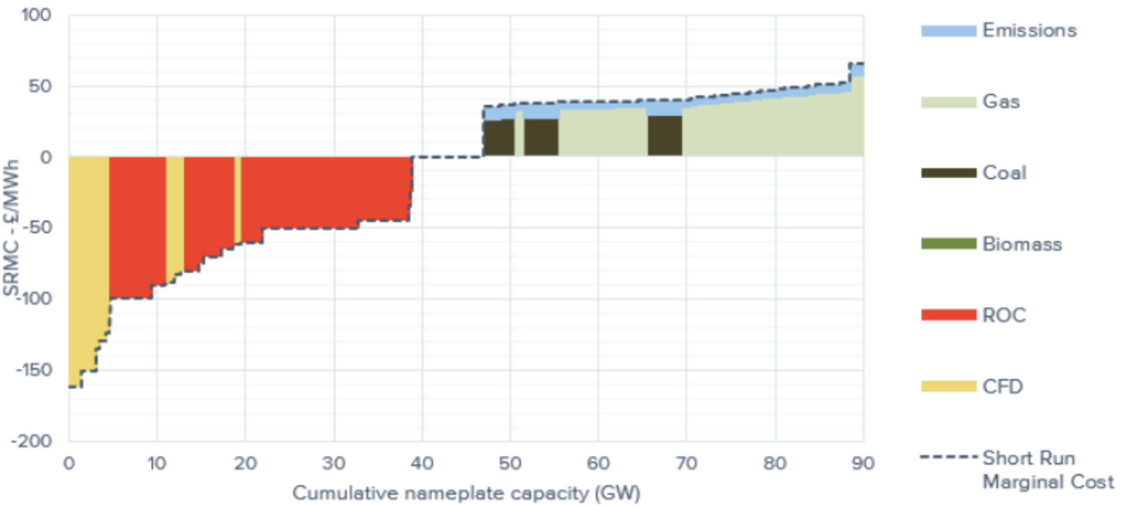

Figure 23 Analysis conducted by Cornwall Insight which illustrates the theoretical minimum bid that a recipient of the RO and the CfD signal to the market and still break event. Source: (Cornwall Insight 2018c).

Informal discussions with representatives of the LCCC have highlighted how the CfD was only intended to be contracted to 20% of the UK's generating fleet. However, current estimates indicate that the CfD may be received by ~30% of the UK's total generation mix by the mid-2020s (LCCC 2020). This means that 30% of the total generating fleet will be financially incentivised to dispatch regardless of market conditions in order to receive their CfD payment, which is likely to depress the wholesale market price. From a holistic lens, this represents an inefficient outcome from GB's primary investment contract which is underpinning the growth in these negative prices. There are growing concerns that the low, and potentially negative, prices will reduce investor confidence in the market (Liebreich 2017; Cornwall Insight 2018c).

Negative prices are also being found within the balancing mechanism. Thermal generators will often bid in positively – indicating a willingness to pay – to be turned down as they can save on fuel costs whilst still receiving the price received in the wholesale market. For VRE, there are no fuel savings and therefore being asked to turn down output does not provide an operational saving; indeed, as CfD and RO payments are based on generation output, being asked to turn down reduces the subsidy payments (National Grid ESO 2011). As such, VRE generators are likely to bid in negative prices into the balancing mechanism – indicating that they want to be paid – to turn down their output. As balancing costs are ultimately paid for in the consumer bill, these negative bids increase the cost to consumers (BEIS 2020d). Not only does this have a financial cost to end consumers, turning down VRE also wastes zero-carbon generation. This issue is further discussed in the constraints and curtailment section below.

BEIS have consulted on proposed amendments to the CfD to reduce the scope for negative prices which are forecast to increase alongside the continued deployment of VRE (Table 14) (BEIS 2020d). Those in receipt of an Allocation Round (AR) 2/3 CfD currently receive their 'strike price' unless there are 6 consecutive negatively priced hours on the N2EX day ahead auction, known as the Intermittent Market Reference Price (IMRP) (BEIS 2020d). The proposed amendment for AR4 would see no strike price being paid for any negative hours on the IMRP (BEIS 2020d). This is hoped to encourage less negative price bidding behaviour, and incentivise generators to be responsive and flexible, which may include deploying storage measures (BEIS 2020d).

There are two concerns with this amendment. First, this alteration is only applied to future CfD contracts, i.e. AR4 onwards, and is not backdated. Therefore, an estimated 18GW of operational capacity will remain under a CfD (AR 1-3) without this amendment (LCCC 2021). Given that negative prices are already evident within the GB electricity market design, this amendment may come too late if the prevention of negative prices is the goal.

Table 14 Summary table on the frequency of forecasted periods of GB DAH hourly negative prices based on various assumptions. Source: (BEIS 2020d).

Scenario	Description	Average annual number of negative day-ahead hours	Average annual number of day-ahead 6+ negative hour periods
Baringa 2015: market	Baringa's central view of the energy system (2020-2035)	2 (~0%)	0
Baringa 2015: Policy	DECC's published policy position (2014) (2020-2035)	48 (~0.5%)	4
BEIS 2019: Central, 30GW of offshore wind by 2030	BEIS current central position, assuming 30GW of offshore wind in 2030 (2025 - 2040)	86 (~1.0%)	2
BEIS 2019: Central, 40GW of offshore wind in 2030	BEIS current central position, assuming 40GW of offshore wind in 2030 (2025 - 2040)	399 (~4.5%)	13

Second, as argued by Pownall et al. (2020), negative prices are either an issue or an opportunity depending on the service provider in question. Negative prices are primarily a concern for load-following generators as this will devalue their output, whereas for flexibility providers these prices can be capitalised on e.g., utilising arbitrate opportunities. As such, negative prices can aid in providing a revenue stream for those units with the flexibility to react.

One of the stated goals of the proposed amendment is to increase the capacity for flexibility in the system, something which is in fact enabled through negative prices. Flexible technologies and flexibility as a service could generate revenue through arbitrage opportunities or by shifting demand to support system stability. At present, as discussed in chapter two, section 2.2.3, routes to market for these services are limited.

Missing money, price cannibalisation, and negative prices in the GB electricity market are likely to become increasingly common with the further deployment of zero-marginal cost generation. National Grid ESO's FES indicate that by 2030 as much as 71% of generation is expected to be based on generators with zero-marginal costs, increasing to 80% by 2050 (BEIS 2020d; National Grid ESO 2020a). These issues will only become more prevalent and a modified electricity market design for GB offers an opportunity to address them.

5.1.3 Constraints and curtailment

Within GB, electricity generators pay to have 'firm'[1] (i.e. 24/7) access to the transmission network, with this constant access meaning that a generator can choose when and how much to generate (House of Commons 2019). However, there are times when generators have to be disconnected by National Grid ESO due to oversupply or localised thermal limit on the transmission network, this is known as curtailment (House of Commons 2019). At times when generators can't access the grid that they have paid to access, they receive compensation in the form of a constraint payment (House of Commons 2019; National Grid ESO 2021c).

The costs of the range of ancillary market services used by National Grid ESO to ensure grid stability are illustrated in Figure 24 – the yellow bars represent constraint payments which amount to more than £715 million for the 2019-2020 financial year. In the end, these costs are socialised and paid for by consumers.

The ESO was intended to be a 'residual' balancer, only taking small actions to ensure that the grid is stable (Ofgem 2021b). However, as is highlighted in Figure 25, the cost of dealing with these constraints has risen significantly since 2015-16 suggesting that it is inaccurate to continue to characterise this as a residual role (Ofgem 2021b). To

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[1] This is registered under the transmission entry capacity (TEC), a register held by National Grid ESO which lists all existing and future connection projects at both the transmission and distribution level (National Grid ESO 2021j).

put this into perspective, the cost of dealing with constraints in 2019-2020 was significantly higher than the £557 million ringfenced in 2017 by the UK government for future CfDs (HM Government 2017). In essence, the financial burden of constraining generation off the network for a single financial year is higher than the allocation of funding to the main support mechanism for the deployment of further large scale, low-carbon electricity generation projects over several years.

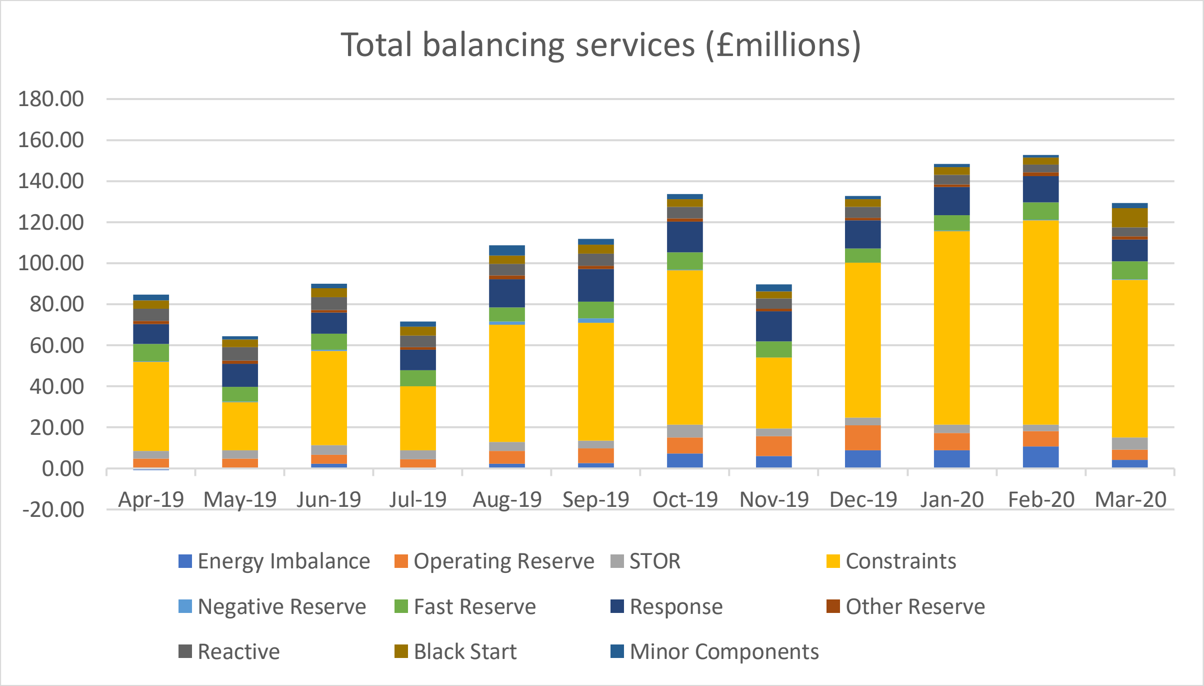

Figure 24 Total balancing services from April 2019-March 2020 in millions, broken down into the constituent costs. Data sourced from MBSS. Data source: (National Grid ESO 2021g).

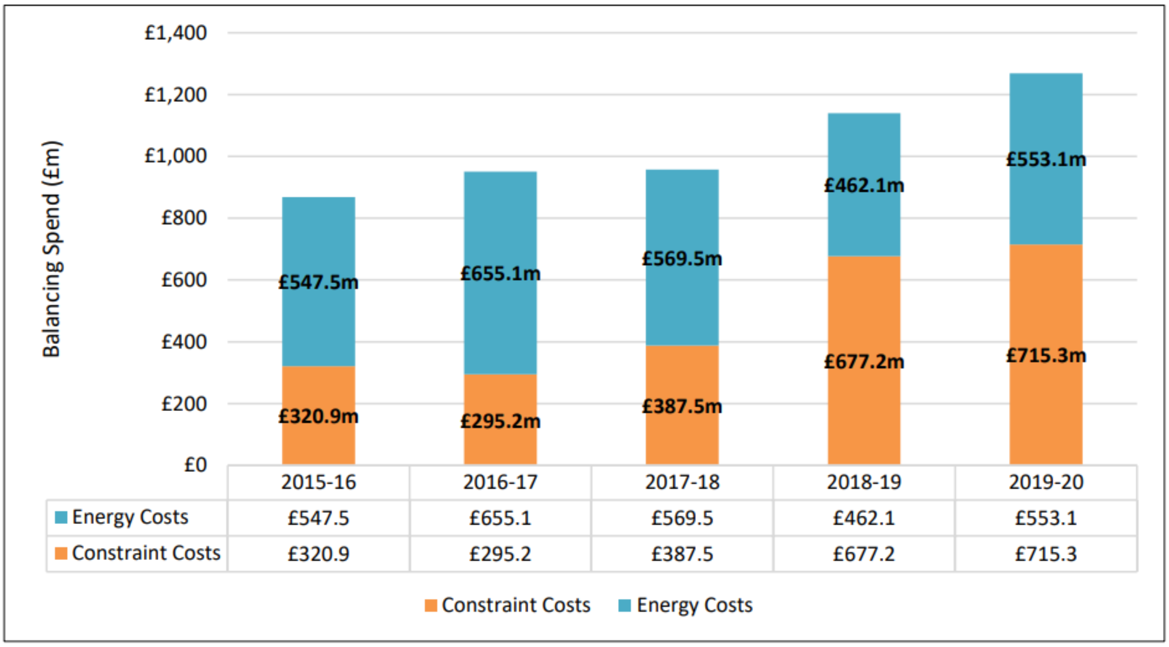

Figure 25 An illustration of the increased spending on system balancing. Note that the constraint cost portion has more than doubled between 2015-16 to 2019-2020. Energy costs relate to balancing supply and demand. Constraint costs refer to managing network flows. Source: (Ofgem 2021b).

Furthermore, the constrained generation is wasted electricity. LCP Energy Analytics (2020a) modelled the impact of constraints across a single boundary between England and Scotland[1] from 2023 to 2030 which forecast that in 2026 managing constraints between this boundary alone would cost more than £1 billion (Figure 26).

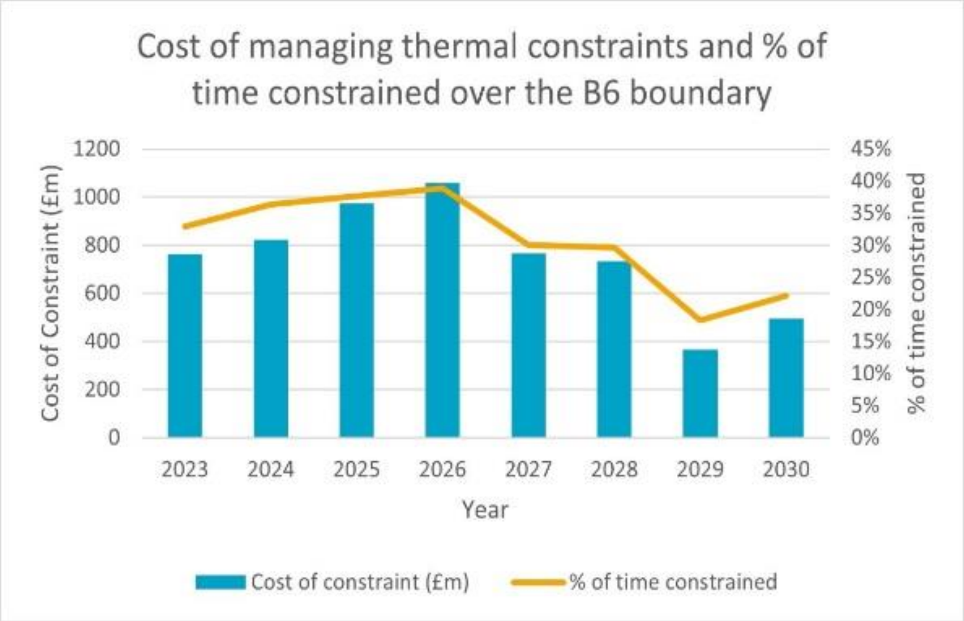

Figure 26 The cost of managing thermal constraints and the % of time constrained on the B6 boundary. Source: (LCP 2020a).

This analysis also modelled the '% of time constrained' which also peaks in 2026 at 40%. In other words, according to this modelling in 2026, 40% of the time generation will have to be constrained off from Scotland into England. This has two negative impacts: First, the constrained generation will likely be zero carbon given the high capacity of both onshore and offshore wind generation connected in Scotland (National Grid ESO 2021d). Second, when constraints are imposed due to capacity or thermal limits at network pinch points, electricity will still be required south of the constraint which will be dispatched via the balancing mechanism. LCP's work suggests that the constrained zero carbon wind power will "almost certainly be replaced with carbon emitting generation south of this boundary" (LCP 2020a: 37). These constraint-inducing limitations bring an additional financial cost to consumers as well as an additional carbon cost due to the dispatch of a thermal asset, which also receives financial compensation for these actions.

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[1] The technical reference for this boundary is 'B6'.

This inefficient outcome from the system, which allows for and indeed financially rewards the curtailment of zero-carbon technologies whilst paying for additional thermal generation to be activated, illustrates how the GB electricity market design is unsuited to increasing levels of VRE. These electrons from zero-carbon sources should not be constrained; one way to avoid this is to increase the level of flexibility on the network, as discussed below.

5.1.4 Lacking liquidity

Liquidity is defined as the "ability to quickly buy and sell a desired commodity or financial instrument without causing a significant change in its price and without incurring significant transaction costs" (Ofgem 2009: 9). A liquid electricity market is vital for market participants, as this allows participants to quickly react to changes in generation or supply by increasing the feasibility to conduct trades in order to mitigate exposure to imbalance charges (ACER 2015; CMA 2015a). However, there are concerns over the level of liquidity within the GB electricity market as reported by the CMA in 2015 (CMA 2015a).

The level of liquidity is an important variable for weather driven technologies who may need to fine tune their market position as more reliable weather forecasts emerge. For example, more or less wind/sun will influence their output and therefore determine if they need to purchase more electricity or sell any excess so that they do not face imbalance charges. A liquid electricity market provides greater opportunities to enact the necessary trade, reducing the risk to these service providers eases this trade and reduces the risk to these generators (Newbery 2013; Ofgem 2019c). The second benefit of a liquid market is the role of price discovery which is enabled through repeated trade on the same product (ACER 2015). As more market participants trade a particular product, more information is revealed about its value which is not only important for price discovery, but the repeated trade itself indicates how the SPOT markets are going to act. Having an understanding of the underlying value of a product will in turn aid in the identification of a reference price which can be used as a signal for long-term investment and hedging strategies (ACER 2015; CMA 2015a).

Given its importance, ensuring liquid electricity markets is an issue which must be addressed in the proposed electricity market design.

5.1.5 Reflecting geographies

The current electricity market design in GB provides limited locational signals as the majority of trading arrangements are settled at a national level (Table 15). At present the GB wholesale market operates under a single price bidding zone with price formation at the national level (Ofgem 2019d). This does not reflect local characteristics such as the scarcity or surplus of electricity at the local level (Nieße et al. 2012; Mengelkamp et al. 2017). Alternative options for the wholesale market are available, such as a zonal or nodal system. The differences between these three approaches are detailed in appendix six, section one.

Under a scenario with increasing levels of decentralised resource providers, regional differences will become increasingly important. As such, the electricity market must be re-designed to take these geographical differences into account.

Table 15 Summary of current market signals within the GB electricity market design and regulation, and whether these contain a locational element. Note that of the top four which are included within the electricity market design, the wholesale market is the largest in terms of value and size highlighting that the largest market does not have a locational element. Table sourced from (National Grid ESO 2021e).

Current market signal	**Locational?**
Wholesale Market	No
Balancing Mechanism	Yes
Capacity Mechanism	No
Contracts for Difference	No
Balancing Services Use of System (BSUoS)	No
Transmission Network Use of System Charges (TNUoS)	Yes
DUoS	Yes
Transmission and Distribution Losses	Yes

Many distributed technologies will be connected to the local distribution networks and the value of, say, a battery will depend partly on its location relative to generation or consumers. Price signals which reflect the value of different locations for technologies or services can guide where they are situated on the network and capacity for these locational signals can be integrated to an electricity market design. Not doing so could exacerbate the already costly interventions required from the balancing mechanism and ancillary market.

Designing the electricity market to account for geographical differences brings many benefits:

- Local balancing can be facilitated through the coordinated deployment of generation and demand on the network. This reduces the distance that electrons must travel and reduces the risk of breaching network capacity, leading to a more efficient use of the network (Mengelkamp et al. 2017; Roques and Finon 2017; WPD 2017; Zhang et al. 2018; Rodriguez-Garcia et al. 2019; Stanley et al. 2019).
- Reflecting 'local' network conditions would signal where on the network value could be realised by providing a specific service e.g. flexibility (Policy Exchange 2020a).
- Solving locational issues with either generating or demand side assets or services in close proximity via a local market would support the assets' integration, helping to retain the profits from these services in the local economy, which may also encourage new investment into DER (Pérez-arriaga et al. 2013; Koirala et al. 2016).

5.1.6 Covid-19 and the distribution gap

The legacy of an electricity market design based upon the characteristics of centralised, large-scale and top-down operation has led to system in GB which lacks an institutional framework at the distribution network - a 'distribution gap'. This distribution gap resulted from this level of the network being considered 'passive', merely drawing power from the transmission level where the majority of centralised generating assets were located. However, as evidenced by chapter one and two, the electricity landscape is undergoing a fundamental shift, with electricity generated on the distribution network increasingly being exported onto the transmission network (National Grid 2015). The existing centralised electricity market design in GB skews the economics of the electricity sector in favour of large generators, limiting the value for services which DER can provide. This can be evidenced by recent events brought about by COVID-19.

International and domestic lockdowns imposed in response to COVID-19 in 2020 led to dramatic shifts in electricity consumption patterns (Bahmanyar et al. 2020;

Edomah and Ndulue 2020; IEA 2020; National Grid ESO 2020f; Norouzi et al. 2020). All European countries (except Sweden which imposed 'soft' confinement measures[1]), experienced a significant overall decline in demand for electricity due to population containment measures (Bahmanyar et al. 2020).

In GB actual electricity demand was ~20% less than National Grid ESO's predictions whilst Q2 2020, saw a 32% increase in the share of renewables compared to Q2 of 2019 (Drax 2020; National Grid ESO 2020g). Higher renewable output led to major challenges in absorbing this variable generation which increased the cost of balancing actions and dampened the wholesale power price (National Grid ESO 2020h; Robinson and Keay 2020). Such trends were expected by 2030 and in this sense the conditions brought about by the response to COVID-19 during the summer of 2020 provided a glimpse into the future electricity sector (Robinson and Keay 2020; National Grid ESO 2021c). This glimpse revealed the inefficiencies within GB's current electricity market design under a scenario with characteristics reflective of a net zero power sector.

The distribution gap was brought to the fore by two events over the summer months of 2020. First, National Grid ESO raised modification *GC0143: Last Resort Disconnection of Embedded Generation* in response to the decrease in demand. Their rationale for the decision was based on forecasts that the inability to control the generation from non-flexible units, such as nuclear and embedded generators, would limit the ESO's ability to ensure the stability of the network (National Grid ESO 2020i). This modification permitted the ESO to instruct a DNO to disconnect embedded generation without financial compensation (National Grid ESO 2020i, 2020f).

As embedded generators have not historically been utilised by National Grid ESO to balance the grid, they do not have a connection agreement with them, and can't be financially compensated if activated; unlike their transmission-connected counterparties who do have such a contractual agreement in place and will be financially compensated (National Grid ESO 2020i). Therefore, if disconnected under GC0143, distribution-connected generators would not receive financial payment despite their service in disconnecting providing value to the network. Again, this skews electricity

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[1] The fact that overall demand remained consistent with pre-Covid-19 levels has been attributed to the decreased demand from certain sectors of the economy, such as transportation, being offset by increases in residential buildings (Zhang et al. 2020b).

economics against DER by introducing a financial risk to generators ‘embedded’ in the distribution network but which their transmission-connected counterparts are not exposed to. Once again evidence an incumbent advantage within GB’s electricity market design.

Whilst GC0143 demonstrates the distribution gap, the introduction of Operation Downward Frequency Management (ODFM), a temporary service introduced by National Grid ESO between May to October 2020, highlighted the valuable role of distributed generating and demand side assets in offering flexibility to balance the grid. Between May to October 2020, GC0143 had not been issued as National Grid ESO designed and implemented ODFM (National Grid ESO 2020j). This temporary service allows National Grid ESO to contract outside of the balancing mechanism with technologies - typically embedded generation - which was previously invisible to National Grid ESO due to the lack of contractual agreement (National Grid ESO 2020j). Over 4.5GW of capacity, predominantly consisting of embedded solar and onshore wind, has signed up to this service with just under 5GW of ODFM being utilised in May 2020 alone (Figure 27) (National Grid ESO 2020j, 2020k). ODFM has demonstrated how distributed VRE generating assets can contribute to balancing services and receive financial compensation for providing this flexibility. This temporary route to market indicated that it is possible to realign the electricity economics and level the playing field.

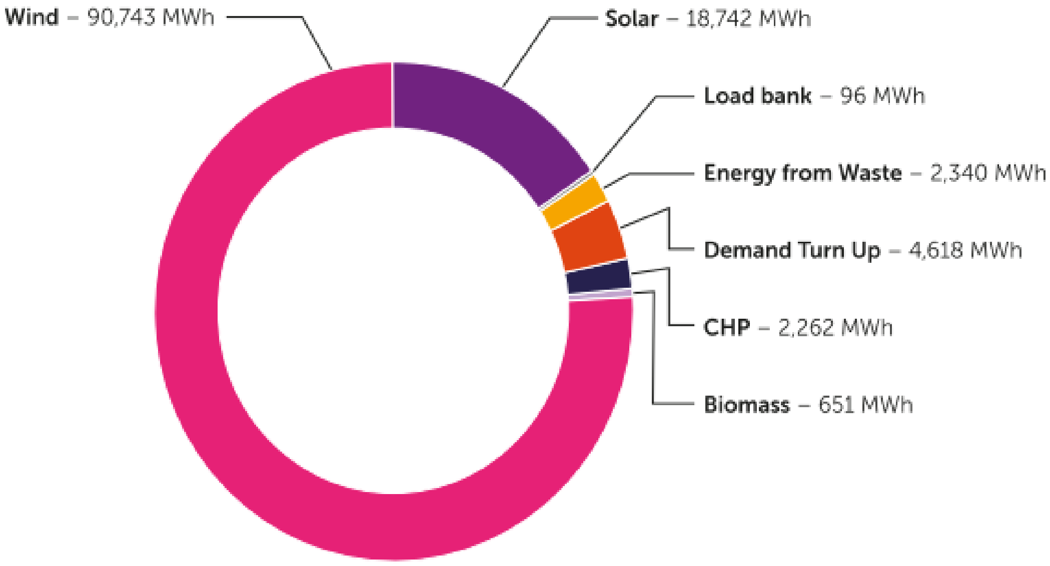

Figure 27 An illustration of the contributing technologies to the 100,000MWh of negative reserve procured under ODFM during the 2020 summer season. The majority of which was provided by wind and solar generation. Source: (National Grid ESO 2021a).

To date electricity economics has provided a more reliable route to market for thermal generators, supporting the case for investment, aiding the lock-in of these generating assets to the disadvantage of their distributed counterparts (Unruh 2000; Meadowcroft 2009a). However, this does not need to be the case. As electricity market designs are social constructs they can therefore can, and has been, reconfigured in response to concerns over the efficacy of the current design as demonstrated by the introduction of ODFM (Fligstein and Calder 2015).

5.1.7 Lacking flexibility

The achievement of national net zero power sector targets is considered to be underpinned by zero carbon, variable and often distributed generation technologies such as onshore wind (NIC 2016; HM Government and Ofgem 2017; Ofgem 2017b; Shakoor et al. 2017; National Grid ESO 2020a). As such, an electricity market design must provide incentives for investment in technologies and services which provide flexibility to complement variable generation (Rosell et al. 2018).

Currently, there are numerous barriers to market entry for flexibility technologies, such as VRE, and services, such as DSR, as has been evidenced throughout chapter two. Mitigating these barriers and opening routes to market for flexibility can unlock the following benefits:

1. Reducing balancing costs through the displacement of more expensive and carbon intensive forms of flexibility, such as open cycle gas turbines (Sanders et al. 2016).
2. Network operators, through schemes such as active network management, can defer or avoid costly network reinforcements by leveraging consumer flexibility to keep within network operating limits (Poudineh and Jamasb 2014; ENA 2015; Spiliotis et al. 2016; Morstyn et al. 2018; Strielkowski et al. 2019).
    a. In the short-term these relatively small investments into flexible demand-side assets can postpone decisions on larger investment until more evidence is available, reducing the scope for making potentially high regret decisions (Sanders et al. 2016; Stanley et al. 2019; Brinkel et al. 2020).

3. Locating flexible services near to, or co-locating with, VRE generation can mitigate the extent of price cannibalisation by absorbing excess VRE and reinjecting at times of increased demand. This reinjection will likely coincide with higher power prices, resulting in a more profitable capture rate (European Commission 2018).
    a. This has an added benefit of reducing network constraints via the removal of the excess electrons from the network. By storing rather than curtailing this zero-carbon generation, the need for carbon intensive generation technologies is minimised (European Commission 2018; Kraan et al. 2019; IRENA 2020).

The Smart Energy System (SES) approach within the literature is one way to increase flexibility and storage capacity (Lund et al. 2016; Rodriguez-Garcia et al. 2019; National Grid ESO 2020a; Sorknæs et al. 2020; Britton et al. 2021). Danish academics and their research into the SES approach which utilises both mobility and heat as flexible load in order to provide cheaper alternatives than an electrical flexibility solution (Lund et al. 2016; Lowes et al. 2020). There are clear associated benefits of a SES approach, but in order to facilitate the deployment of these flexible demand-side assets there needs to be a clear route to market which identifies the value for their services (Lund et al. 2016; Lowes et al. 2020; Sorknæs et al. 2020; Pownall et al. 2021).

In utilising embedded demand-side assets for their flexibility, ODFM (and indeed other trials such as WPD’s Electric Nation (Electric Nation Project 2019), Oxfordshire’s Project LEO (Oxford City Council 2019) and those awarded Innovate UK funding for Vehicle to Grid services (BEIS and OLEV 2017) demonstrates the feasibility and value of providing additional flexibility to the network (National Grid ESO 2020a).

5.1.8 Lacking transparency and market manipulation

In 2019 83.6% of GB electricity was traded bilaterally, in which the prices for which are not within the public domain, only accessible through a subscription to a price reporting agency (Table 4)(Ofgem 2016d, 2019e; Elexon 2020). This opaque structure dampens investment signals as the financial compensation received for a service is not known, it also risks cost sub-optimality as the cheapest technology may not always be dispatched (Cramton 2017; Lin and Magnago 2017). The lack of transparency does not aid in reducing the sorts of manipulative market practices which are discussed in the next section.

Ofgem, under EU's Regulation on Wholesale Energy Market Integrity and Transparency (REMIT)[1], is responsible for the integrity and transparency of the wholesale energy market. The regulation defines market abuse and provides Ofgem with the agency to issue financial penalties for market manipulative practices (Ofgem 2021b). Under REMIT financial penalties have been issued to InterGen, EDF and most recently ESB Independent Generation Trading Limited for market manipulative practices (ACER 2021; Ofgem 2021c).

InterGen was found to have sent misleading signals to National Grid ESO in 2016 about how much electricity their units could supply during peak winter demand periods (Ofgem 2020c). This misleading signal led National Grid ESO to believe that there was less generation available, driving up prices and allowing InterGen to make a substantial profit of £12.8 million (Ofgem 2020c). Intergen paid £37.3 million to Ofgem (Ofgem 2020c). Both EDF Energy and ESB Independent Generation Trading Limited also sent misleading technical data to National Grid ESO, again leading to the increased procurement of electricity which was supplied by EDF themselves in the former instance (Ofgem 2020d). EDF and Independent Generation Trading Limited both paid £6 million to Ofgem (Ofgem 2020d, 2021c).

These instances of market manipulation highlight how bilateral trading has not eliminated these practices since NETA. This raises serious concerns about the current market design within GB considering that one of the fundamental pillars for NETA, and a justification for moving away from the Pool market, was to reduce market manipulative practices (As explained in chapter two, section 2.1.1).

5.1.9 The capacity market

As a result of the indiscriminate approach to procuring capacity, the capacity market undermines the decarbonisation of the electricity sector for a number of reasons:

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[1] Ofgem's REMIT role will still function post Brexit (Cornwall Insight 2021d).

The decision not to exclude coal: This has a twofold impact: First, by competing and securing contracts coal[1] power plants are kept on the grid rather than phasing out this highly carbon intensive technology (IEA 2016). Second, by competing they are removing capacity which may otherwise be secured by technologies and services that are in line with net zero.

Amortising CCGT: As illustrated in Figure 28, the vast majority of capacity market contracts have been secured by CCGT plants, with relatively small levels of capacity being paid to technologies and services considered to be aligned with net zero such as DSR and energy storage.

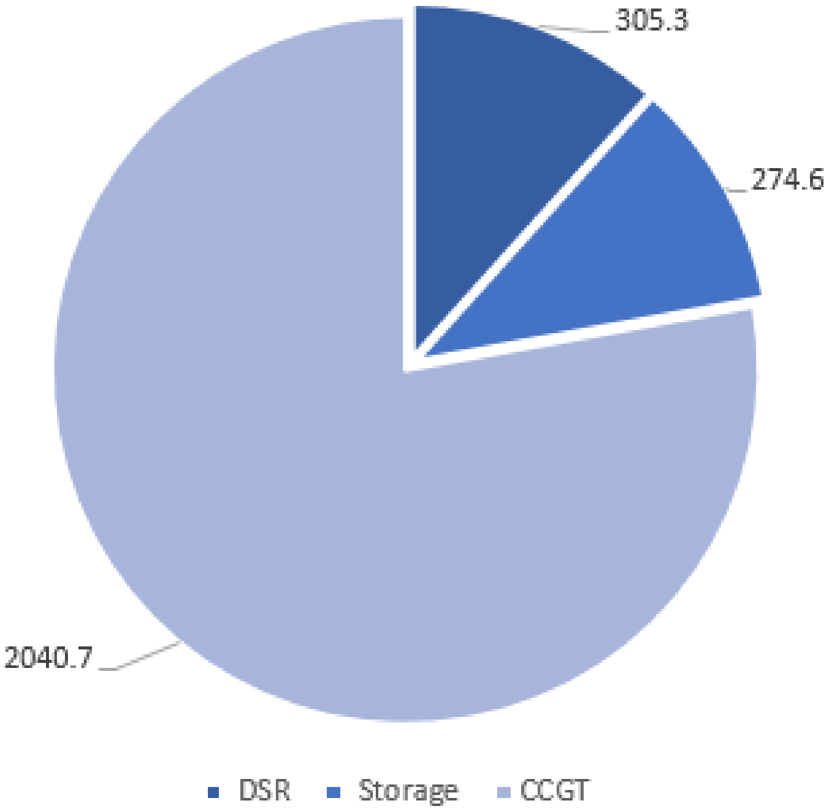

Figure 28 Total funding allocation for DSR, Storage and CCGT within capacity market auctions between 2015-2021. All figures are in £millions. * = The T-4 auction held in 2021 group CCGT, OCGT and possibly reciprocating engines, under a single title of 'gas' and therefore the value of CCGT presented here represents the highest possible value. Data sourced:* (National Grid ESO 2021k).

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[1] It should be noted that for certain capacity market auction results coal and biomass have been combined, decreasing the transparency of the contributions from coal sources. For example, see (National Grid 2017b). This is likely due to coal-biomass conversion of Drax plants.

Limited success in driving new capacity onto the grid: As explained in chapter two, section 2.2.1.4, the capacity market has done little in the means of incentivising new build generation, but instead the majority of funding has been allocating to existing, and often fossil fuelled, generators (Figure 7).

Treatment of DSR: In 2020 BEIS held a consultation on future improvement of the capacity market (BEIS 2020f). Within this they acknowledge the need to alter the design to better suit the incorporation of DSR. For example, in the 2020 T-4 Auction coal secured 3.02% capacity whereas DSR only secured 2.67% or 1.1GW (National Grid ESO 2020l). This is a fraction of the 9.8GW of DSR estimated to be available by the ADE from industrial, commercial and the public sector (ADE 2016). Previously, DSR could only access one-year capacity mechanism contracts whereas other forms of capacity have access to longer contracts which can aid in the securing of cheaper debt financing. This has now been altered to allow DSR access to longer term capacity payments, but the impact of this remains to be seen at the next capacity market auction. This represents a likely bias against the demand-side, and a preference for generating to meet security of supply as opposed to engaging with the active demand side which offers another means to provide security of supply.

Treatment of VRE: VRE technologies are largely exempt from competing in the capacity market auction due to a State Aid clause which does not allow those in receipt of a subsidy, such as the CfD and RO, to enter into the capacity market (BEIS 2018b). Whilst this currently excludes the majority of VRE technologies, the first RO contracts expire in 2027, with several CfD contracts expiring in 2031. This would allow these assets to be eligible in actions in 2023 and 2027 respectively. This has led to BEIS to re-consider their current de-rating factors[1] (BEIS 2018b). These de-rating factors, as illustrated in Table 16, represent the lower confidence that central government holds for variable renewable technologies in providing system security. The Power Responsive campaign, a subsidiary of National Grid ESO which aims to incentivise the utilisation of DSR, have stated that the de-rating factors for demand-side flexibility within the capacity market

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[1] A metric applied by BEIS which represents their confidence in a particular technology in contributing to the security of the system.

limit revenues (National Grid ESO 2021c). Coming from a subsidiary, this is an especially powerful criticism of the systematic undervaluing of DSR in the capacity market.

Table 16 De-rating factors. Source for first group: (National Grid ESO 2018b)*. Source for second group:* (National Grid ESO 2019f)*. * indicates that the 96.11% is not for all forms of storage, but this differs depending on durations of the storage unit with the 96.11% reserved for 4+ hours, with the 0.5 hours de-rated to 17.89%* (BEIS 2017a)*.*

Name for technology class	**Derating factors T-4**	**Name for technology class**	**Derating factors T-4 2023/24**
oil-fired steam generators	88.04%	**Onshore wind**	8.20%
OCGT and reciprocating engines (non-auto generation)	94.81%	**Offshore wind**	12.11%
Nuclear	85.24%	**Solar PV**	1.56%
Hydro	87.92%		
Storage	96.11%*		
CCGT	90.00%		
CHP and auto generation	90.00%		
Coal/biomass	87.58%		
DSR	86.34%		

There is scope for increasing the de-rating factor of VRE technologies by combining wind and solar together in ‘hybrid’ generation projects to improve security of supply, such change would require legislative amendments (BEIS 2018b). The Government (BEIS 2018b) is also considering stronger penalties to encourage the deployment of these hybrid projects. However, it would appear counterintuitive to introduce penalties which inherently disfavour VRE technologies under an electricity market design which is to be based upon increasing shares of VRE.

Undermining flexible generation/services: Times when low cost (e.g. VRE) generation is unavailable and more expensive generators are dispatched, causing prices to rise sharply, are labelled ‘scarcity events’. With the advent of the capacity market, designed to secure system adequacy, the frequency of scarcity events has fallen within the GB wholesale market (Green Alliance 2016; Energy Systems Catapult 2019). These scarcity events provide revenue streams for flexible technologies and services who are able to reduce demand during these high-priced events, or generate an income based on the arbitrage opportunities (Pierpont and Nelson 2017; Leslie et al. 2020). The loss of these events can be harmful for flexible generators and service providers (Energy Systems Catapult 2021).

Designed for large-scale participants: In Ofgem's' (2019a) five-year review of the capacity market reflected on how this mechanism was initially design for large-scale assets For example, the pre-qualification stage is resource intensive and complex in order to provide delivery assurances; in the context of strong interest from smaller projects looking to receive a capacity market payment these are a barrier and no longer appropriate (Ofgem 2019a; Đukan and Kitzing 2021). In addition, there is a minimum clip size of 2MW required to enter the capacity market. Though this can be achieved via aggregation (DECC 2013), it nonetheless represents a barrier to smaller market participants. Finally, in order to receive a multi-year contract, one must reach a certain spending threshold (BEIS 2020f).

Energy efficiency: Electricity demand is decreasing in part due to energy efficiency measures (Ofgem 2020a; BEIS 2021b). Reducing peak electricity demand also reduces the requirement for additional capacity or demand shifting to ensure grid stability. This in turn reduces the cost of capacity payments as these technologies and services are not required. However, energy efficiency has been trialled for integration into the capacity market, via the electricity demand reduction (EDR) pilot. BEIS concluded that the EDR would not be viable in the GB capacity market on the grounds that the pilot only had a few interested parties and may therefore be underutilised if incorporated into the capacity market, and that the bidding was more expensive than the clearing prices of the capacity market (BEIS 2019b). The EDR trial made around £10 million available in payments for the piloting (BEIS 2019c), a fraction of what is paid out to generating technologies. This imbalance and focus on generation is characteristic of the continuing load-following management mind-set in the GB electricity sector.

5.2 Issues identified by data collection

Of the 41 participants interviewed, a total of 31 respondents provided clear evidence of issues stemming from the current electricity market design within GB.

Analysis of the interview transcripts identifies several key issues with GB's current electricity market design (Figure 29). The issues raised by participants can be themed into distinct groupings many of which reflect the issues discussed within the previous section:

- An outdated electricity market design
- Investment signals not coming through
- Not a level playing field between technologies and market participants
- Complexities within the market design
- Lack of transparency
- Lack of coordination

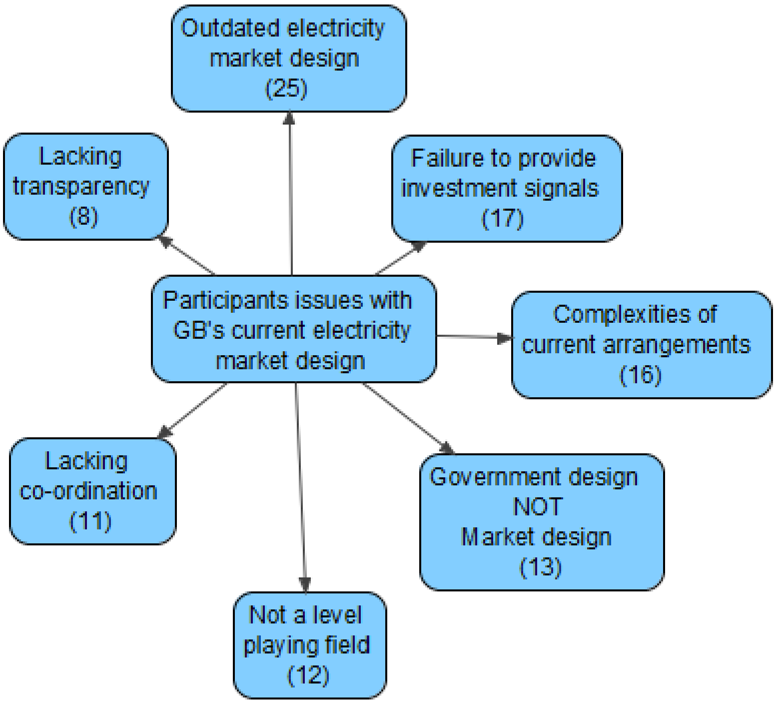


Figure 29 Visualisation of the participant issues with the current electricity market design. The theme of outdated market design is further explored as there are many elements to this issue which can't be summed into one node. Number in brackets refers to the number of participants who could be themed into this category.

The most prominent theme, mentioned in two thirds of responses, was that the electricity market design in GB is outdated as the energy system has undergone rapid change since NETA whilst the market design itself largely remains the same. The mismatch between the electricity system for which the market was designed and the system now is a primary cause of the problems identified within the literature review.

The precise ways in which GB's current market design is 'outdated' can be isolated and doing so highlights that the outdated market design is fundamental to many other concerns put forward by the participants (Figure 30).

> "I think it's more just a structural thing of the technology is changing, and the physical placement of the assets is changing and therefore that the old model's is no longer fit for purpose because it doesn't let you achieve whole system value"
>
> Interview 13

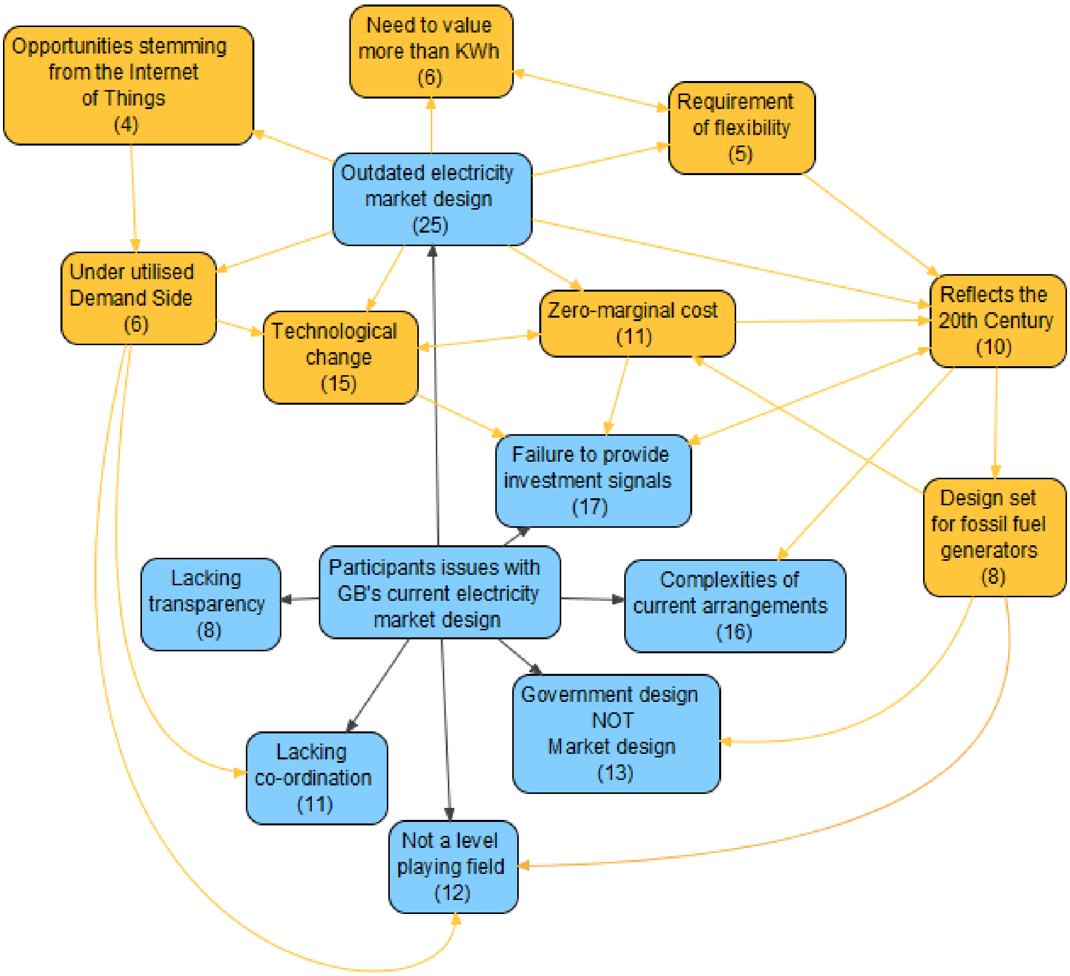


Figure 30 The outdated design within Figure 29 Visualisation of the participant issues with the current electricity market design. The theme of outdated market design is further explored as there are many elements to this issue which can't be summed into one node. Number in brackets refers to the number of participants who could be themed into this category.

The 'outdated design' is an umbrella term comprising several interrelated aspects which have had a cumulative effect and underpin many of the other problem's participants identified with GB's current electricity market design.

5.2.1 Identifying trends in the issues put forward by interviewees

Through identifying the experts and market participants who attested to the different issues, it is possible to understand which issues are pertinent to different participants – see Figure 31.

A review of the market parties reveals patterns of convergence and divergence in their concerns. An area of convergence in concerns between many market parties is that GB’s current electricity market design fails to provide bankable signals required to justify an investment case (Figure 31). This specifically related to the transition to a zero-marginal cost regime which fundamentally differs from current practices and is creating additional risk for investors.

However, an area of divergence appears in the extent to which GB’s electricity market design is considered ‘not a level playing field’ and the perception that ‘complexities’ in the current market design are problematic. Both of these nodes are populated by the smaller players operating in the market or those involved with the governance of the market design. It is worth noting that a party absent from these discussions are the incumbent energy suppliers, with the exception of an incumbent energy trader who acknowledged that the current market design is favourable to those of an incumbent status.

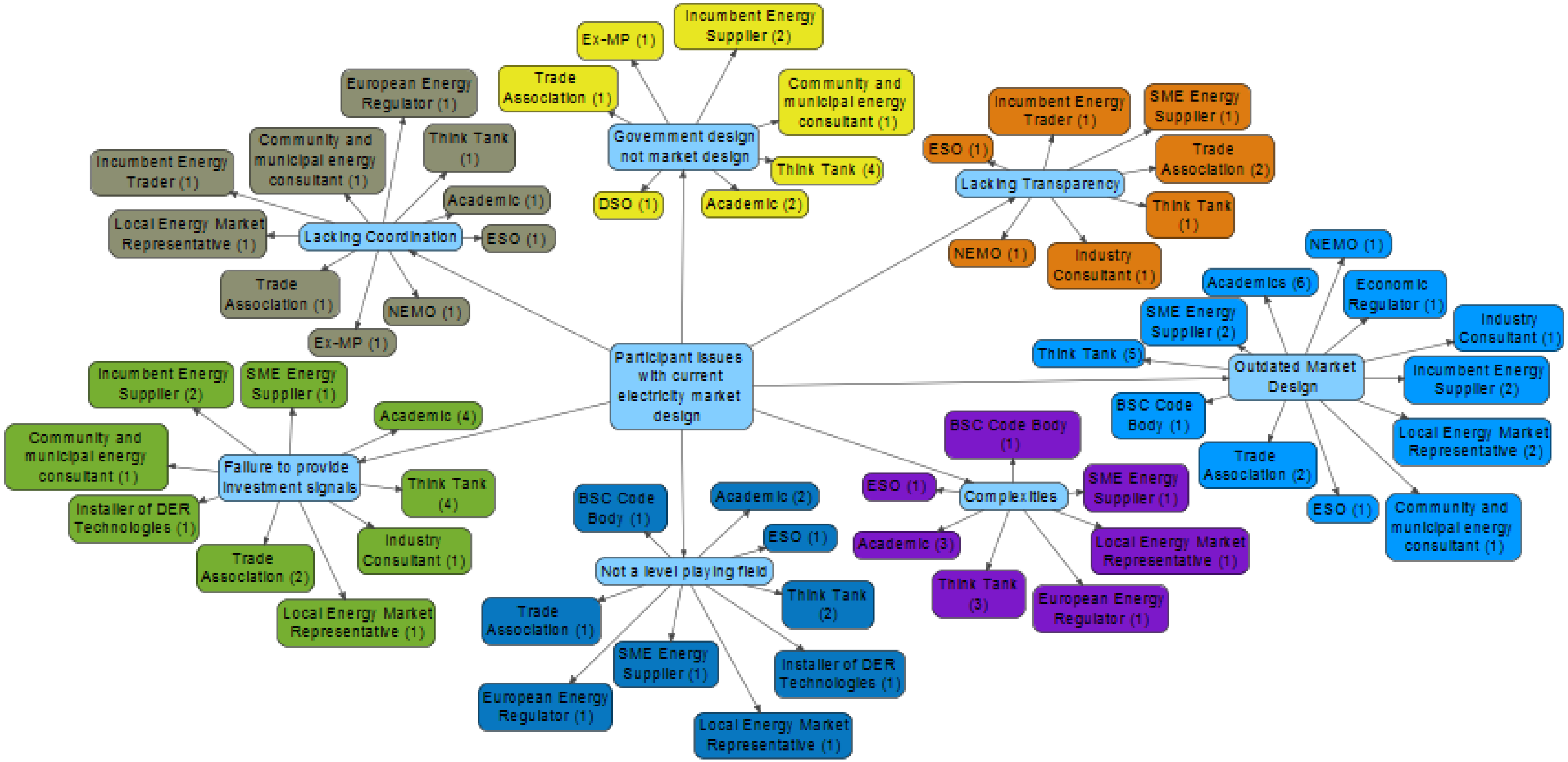


Figure 31 Summary of the key themes of issues within the current electricity market design split into the industry groups who raised these issues. Number in bracket shows the number of participants within the industry grouping that are included.

5.2.2 Placing these issues into their market modules

The issues highlighted via stakeholder interviews thus far can be attributed to specific market design modules and perceived misalignments between these modules (Figure 32). For example, many concerns emerged throughout these interviews on the issues of the capacity market, being a marketplace, which amortises fossil fuel technologies or concerns that there is a 'missing module', typically referring to a local marketplace.

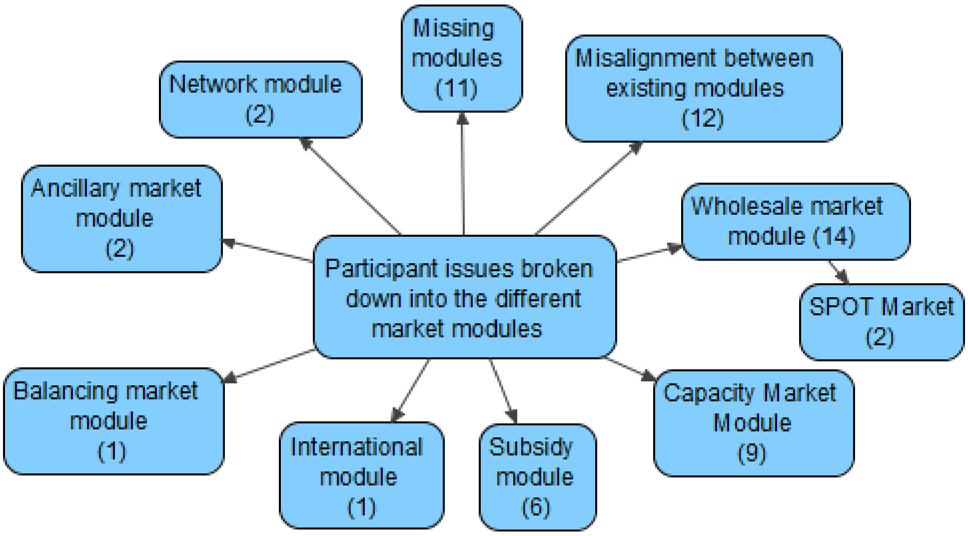


Figure 32 An illustration of the issues of the participants within the current market model placed under their respective module. Number in brackets refers to the number of participants who could be themed into this category.

The top three concerns related to misalignment between existing modules; the wholesale market module; and instances where participants identified that an additional module was required.

There was a common concern among those highlighting the misalignment of modules regarding how the electricity market design in GB had been re-configured since the inception of NETA in 2001. Specifically, that individual modules had been re-configured in small ways to resolve a particular problem which did not address the underlying causes, creating a fragile market design which fails to give confidence to investors. This was especially evident from interviews with an economist (Interview 12), community and municipal energy consultant (Interview 22), an energy regulator at an

SME energy supplier (Interview 20), and an incumbent energy supplier (Interview 23). These views can be expressed by a quote from Interview 12:

> "When you have got a market structure which is so, inadequate as the one today is and you start to build bits and pieces of capacity markets and other markets on top of it, it becomes an evidently fragile investment instrument."

Interview 12

With regard to the current wholesale market, interviewees felt the module was inappropriately designed for the characteristics of new technologies coming online. In particular, respondents described how large amounts of zero-marginal cost generation were leading to lower wholesale prices which hinder investment opportunities (Interview 7, 12, 23-24), as well as predicting increased price cannibalisation under current wholesale market arrangements (Interview 12).

Third, several participants identified a gap within GB's current electricity market design and proposed an additional module. The need for a module which facilitated the integration of locational information within the market design was the most commonly identified alteration, e.g. the introduction of a local energy market. Therefore, we can see how it is possible to attribute certain issues with the current electricity market design to specific modules and the (mis)alignment between these modules.

5.3 Alternative proposals for the electricity market design the themes from this data collection

As demonstrated thus far, there are many concerns with the efficacy of GB's electricity market design. As such, the academic and grey literature contains many proposed reconfigurations to the institution. A review and analysis of 49 papers with proposals for electricity market reform from liberalised countries experiencing similar issues as GB published since 2004 was undertaken to understand the state of knowledge and direction of the debate within this field of literature. Figure 33 is a screenshot of the spreadsheet which contains the proposals reviewed and their different features. This is not the full spreadsheet which has been uploaded as an excel file as appendix four to allow the reader to go into greater depth on the designs reviewed.

The X-axis of the spreadsheet details:

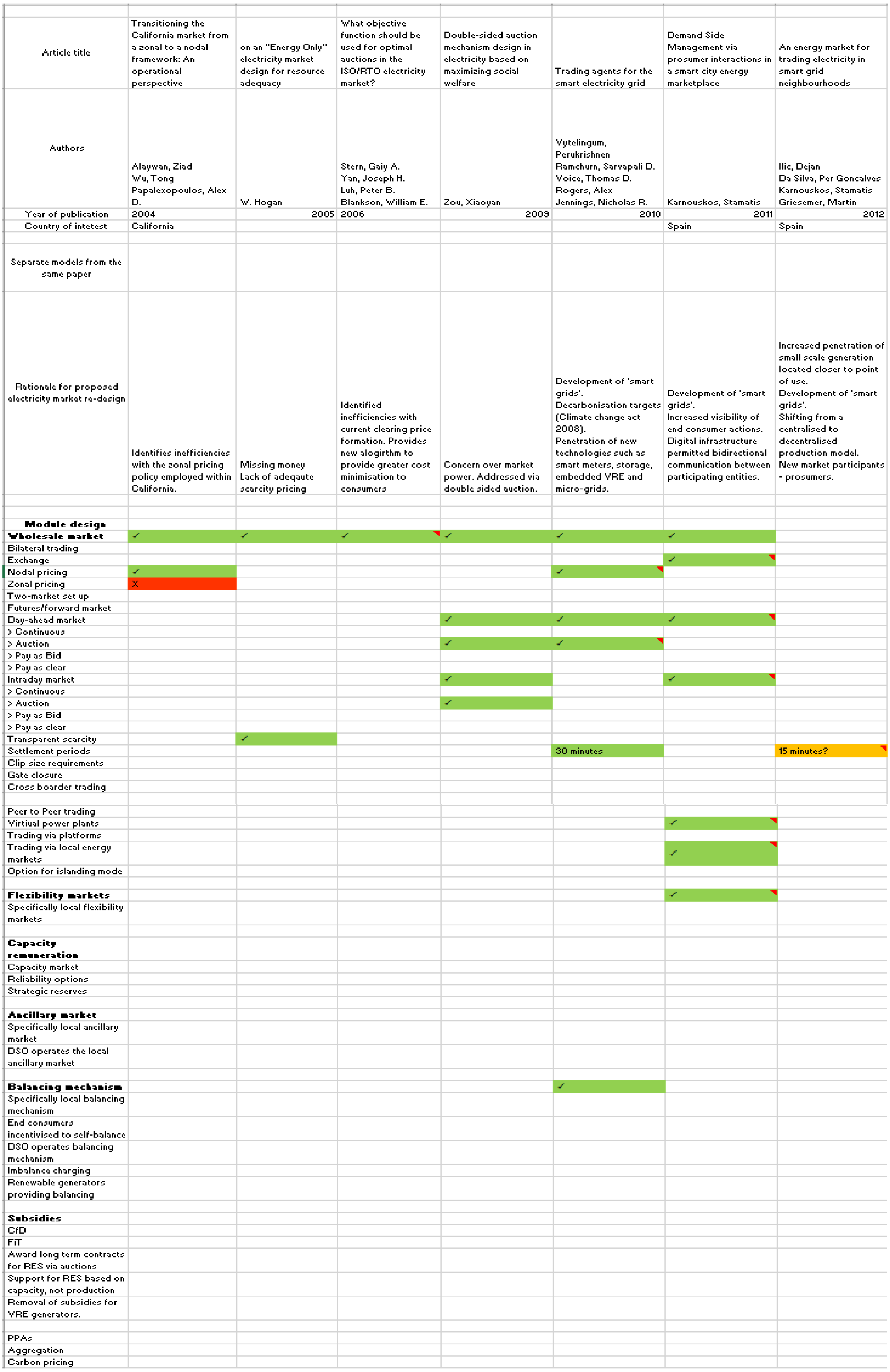
1. The title of the article
2. The authors
3. The year of publication
4. A country of interest (if applicable). Some proposals are based upon case studies within a given region or are set out to solve an issue bespoke to an electricity market design of a particular country or state.
5. The final row cites the author(s)' rationale for electricity market re-design.

The Y-axis lists the different modules and breaks each of these down into features. For example, within the wholesale market module this is deconstructed into whether trades are conducted on a bilateral basis or via an exchange.

Each cell is colour coded:

- Green cell: this is a feature discussed within the proposal.
- Orange cell: it was unclear whether this feature was present within the design. Certain features were hinted at but not confirmed, hence the '?'.
- Red cells: this was a feature identified as being removed or excluded within the proposal.
- Empty cells: there was no mention of this feature within the proposed design. The scale of empty cells within this spreadsheet re-affirms the gap identified within chapter two, in the need for a holistic electricity market re-design to be proposed.

Certain cells have a purple icon in the top right-hand corner which indicates that a comment is attached to that cell. These comments provide additional information beyond the indication of presence or absence.



Article title	Transitioning the California market from a zonal to a nodal framework: An operational perspective	on an "Energy Only" electricity market design for resource adequacy	What objective function should be used for optimal auctions in the ISO/RTO electricity market?	Double-sided auction mechanism design in electricity based on maximizing social welfare	Trading agents for the smart electricity grid	Demand Side Management via prosumer interactions in a smart city energy marketplace	An energy market for trading electricity in smart grid neighbourhoods
Authors	Alaywan, Ziad Wu, Tong Papalexopoulos, Alex D.	W. Hogan	Stern, Gaiy A. Yan, Joseph H. Luh, Peter B. Blankson, William E.	Zou, Xiaoyan	Vytelingum, Perukrishnen Ramchurn, Sarvapali D. Voice, Thomas D. Rogers, Alex Jennings, Nicholas R.	Karnouskos, Stamatis	Ilic, Dejan Da Silva, Per Goncalves Karnouskos, Stamatis Griesemer, Martin
Year of publication	2004	2005	2006	2009	2010	2011	2012
Country of intetest	California					Spain	Spain
Separate models from the same paper							
Rationale for proposed electricity market re-design	Identifies inefficiencies with the zonal pricing policy employed within California.	Missing money Lack of adeqaute scarcity pricing	Identified inefficiencies with current clearing price formation. Provides new alogirthm to provide greater cost minimisation to consumers	Concern over market power. Addressed via double sided auction.	Development of 'smart grids'. Decarbonisation targets (Climate change act 2008). Penetration of new technologies such as smart meters, storage, embedded VRE and micro-grids.	Development of 'smart grids'. Increased visibility of end consumer actions. Digital infrastructure permitted bidirectional communication between participating entities.	Increased penetration of small scale generation located closer to point of use. Development of 'smart grids'. Shifting from a centralised to decentralised production model. New market participants - prosumers.
Module design							
Wholesale market	✓	✓	✓	✓	✓	✓	
Bilateral trading							
Exchange						✓	
Nodal pricing	✓				✓		
Zonal pricing	X						
Two-market set up							
Futures/forward market							
Day-ahead market				✓	✓	✓	
> Continuous							
> Auction				✓	✓		
> Pay as Bid							
> Pay as clear							
Intraday market				✓		✓	
> Continuous							
> Auction				✓			
> Pay as Bid							
> Pay as clear							
Transparent scarcity		✓					
Settlement periods					30 minutes		15 minutes?
Clip size requirements							
Gate closure							
Cross boarder trading							
Peer to Peer trading							
Virtiual power plants						✓	
Trading via platforms							
Trading via local energy markets						✓	
Option for islanding mode							
Flexibility markets						✓	
Specifically local flexibility markets							
Capacity remuneration							
Capacity market							
Reliability options							
Strategic reserves							
Ancillary market							
Specifically local ancillary market							
DSO operates the local ancillary market							
Balancing mechanism					✓		
Specifically local balancing mechanism							
End consumers incentivised to self-balance							
DSO operates balancing mechanism							
Imbalance charging							
Renewable generators providing balancing							
Subsidies							
CfD							
FiT							
Award long term contracts for RES via auctions							
Support for RES based on capacity, not production							
Removal of subsidies for VRE generators.							
PPAs							
Aggregation							
Carbon pricing							

Figure 33 A screenshot of appendix three. This illustrates a snapshot of the different proposals which were reviewed.

The review identified a distinct shift in the rationale for the need for a reconfiguration to the electricity market design around 2009/2010. Designs from 2004-2009 focused on rectifying economic inefficiencies within an aspect of market design at that time. In contrast, designs proposed from 2010-2022, whilst still wanting to increase the institutions efficacy, have sought primarily to capitalise on the opportunities and resolve the problems presented by the transitioning electricity sector.

Pre-2010 – bettering the efficacy of the current market design:

The imperfections addressed stem from inefficiencies in the economic methodology employed within the market design; recommendations consisted of preferred economic solutions to their perceived issue (Table 17).

Table 17 Rationale for re-design and proposed solution identified between 2004 and 2009.

Rationale for Re-design	Proposed solution	Refs
Increased costs of re-dispatch due to inefficient decentralised zonal pricing mechanism	Zonal to nodal	(Alaywan et al. 2004)
Missing money phenomenon	Incorporation of transparent scarcity pricing in an energy-only market	(Hogan 2005b)
Inefficient market clearing price	Updated algorithm to optimise auctions	(Stern et al. 2006)
Concerns over scope for abuse of market power	Implementation of double-sided auction mechanism	(Zou 2009)

From 2010 there are a significant increase in market design publications

Proposed market designs since 2010 have adopted a broader remit in trying to take advantage of the benefits and address the emergent challenges of a fundamentally different electricity system.

Table 18 Rationale for re-design and proposed solution identified between 2010 and 2021.

Rationale for re-design	Refs
Deployment of VRE	(Vytelingum et al. 2010; Yi et al. 2013; Mihaylov et al. 2014; Riesz and Milligan 2015; Neuhoff et al. 2016; Parag and Sovacool 2016; Hogan et al. 2016; Ashouri et al. 2017; Bielen et al. 2017; Mengelkamp et al. 2017; Newbery 2017; Peng and Poudineh 2017; Roques and Finon 2017; Gimon 2017; Keay and Robinson 2017; Rosell et al. 2018; De Vries and Verzijlbergh 2018; Esmat et al. 2018; Joos and Staffell 2018; Xu 2019; Energy Systems Catapult 2019, 2021; Leslie et al. 2020; Savelli and Morstyn 2020)
Intermittency of VRE	(Yi et al. 2013; Riesz and Milligan 2015; EcoGrid 2016; Mengelkamp et al. 2017; Pierpont and Nelson 2017; Gerard et al. 2018; Joos and Staffell 2018; Zhang et al. 2018)
Flexibility required	(Yi et al. 2013; Ashouri et al. 2017; Newbery 2017; Roques and Finon 2017; De Vries and Verzijlbergh 2018; Gerard et al. 2018; Xu 2019; Energy Systems Catapult 2021)
Deployment of DER	(Ilic et al. 2012; Mihaylov et al. 2014; Hogan et al. 2016; Kristov et al. 2016; Neuhoff et al. 2016; Ashouri et al. 2017; De Wit 2017; Peng and Poudineh 2017; Mengelkamp et al. 2017; Rosell et al. 2018; Zhang et al. 2018; Gerard et al. 2018; Stanley et al. 2019; Savelli and Morstyn 2020; Papalexopoulos et al. 2020)
Deployment of Storage	(Vytelingum et al. 2010; Mihaylov et al. 2014; Pierpont and Nelson 2017; Morstyn et al. 2018; Zhang et al. 2018; Savelli and Morstyn 2020)
Introduction of new market participants	
Prosumers	(Ilic et al. 2012; Mihaylov et al. 2014; EcoGrid 2016; Hogan et al. 2016; Ilieva et al. 2016; Parag and Sovacool 2016; De Wit 2017; Rosell et al. 2018; Zhang et al. 2018; Morstyn et al. 2018, 2020; Papalexopoulos et al. 2020)
EVs	(Liu et al. 2018; Rosell et al. 2018; Papalexopoulos et al. 2020)
Deployment of DSR	(Kristov et al. 2016; Market4Res 2016; Bielen et al. 2017; De Wit 2017)
aggregators	(EcoGrid 2016; Ilieva et al. 2016; Kristov et al. 2016; Market4Res 2016; Neuhoff et al. 2016; Bielen et al. 2017; Newbery 2017; Peng and Poudineh 2017; Gimon 2017; Keay and Robinson 2017; Rosell et al. 2018; Esmat et al. 2018; Morstyn et al. 2018; Xu 2019)
New modes of operation unlocked by IoT	(Karnouskos 2011; Mihaylov et al. 2014; Hogan et al. 2016; Newbery 2017; Pierpont and Nelson 2017; Zhang et al. 2018; Energy Systems Catapult 2019; Papalexopoulos et al. 2020; Savelli and Morstyn 2020)

	Home automation tech / Smart meters	(Vytelingum et al. 2010; Mihaylov et al. 2014; EcoGrid 2016; Kristov et al. 2016; Market4Res 2016; Parag and Sovacool 2016; Zhang et al. 2018)
	Blockchain	(Mihaylov et al. 2014; De Wit 2017; Mengelkamp et al. 2017)
	P2P	(Riesz and Milligan 2015; Kristov et al. 2016; Parag and Sovacool 2016; Mengelkamp et al. 2017; Morstyn et al. 2018, 2020; Zhang et al. 2018; Papalexopoulos et al. 2020)
	local balancing	(Mihaylov et al. 2014; EcoGrid 2016; Ilieva et al. 2016; Kristov et al. 2016; Parag and Sovacool 2016; Mengelkamp et al. 2017; Roques and Finon 2017; Esmat et al. 2018)
	Microgrids	(Riesz and Milligan 2015; EcoGrid 2016)
Two-way flow of generation		(Karnouskos 2011; Zhang et al. 2018; Savelli and Morstyn 2020)
Efficacy of wholesale market		
	National markets not reflecting local scarcity	(Riesz and Milligan 2015; Energy Systems Catapult 2021)
	Price cannibalisation	(Blyth et al. 2020; Cornwall Insight 2020a)
	Penetration of low or zero SRMC	(Bielen et al. 2017; Gimon 2017; Keay and Robinson 2017; Mengelkamp et al. 2017; Newbery 2017; Pierpont and Nelson 2017; Leslie et al. 2020)
	Investment concerns based upon current electricity market design	(Keay and Robinson 2017; Pierpont and Nelson 2017; De Vries and Verzijlbergh 2018; Energy Systems Catapult 2019, 2021; Blyth et al. 2020; Cornwall Insight 2020a)
	Rising congestion costs	(Liu et al. 2018; Policy Exchange 2020a)
European Regulation		(Newbery 2017; Pierpont and Nelson 2017; Roques and Finon 2017; Gerard et al. 2018; Xu 2019)
Avoid network reinforcement costs		(Mengelkamp et al. 2017; Esmat et al. 2018; Morstyn et al. 2018; Rosell et al. 2018; Stanley et al. 2019)
Increased demand for electricity		(Bielen et al. 2017; Esmat et al. 2018)
Decarbonisation goals		(Vytelingum et al. 2010; Yi et al. 2013; Joos and Staffell 2018; Liu et al. 2018; Energy Systems Catapult 2019, 2021)

Comparing Table 17 and Table 18, the rationale for the reconfiguration of an electricity market design has evolved since 2010. Whilst economic efficiency is a priority throughout, Table 18 demonstrates how the rationale for change has become more complex due to the new characteristics of the transitioning energy system.

When comparing the proposed solutions in Table 17 and those in Table 18 there are several key differences:

1) Table 18 proposes reconfigurations utilising concepts which were not present during the previous time period of Table 17.
2) Table 18 requires flexibility to counterbalance VRE generation, a concern not present in Table 17 due to the prominence of dispatchable technologies.
3) Table 18 proposes reconfigurations at both the distribution and transmission network whereas Table 17 solutions are based on the transmission network.
4) As proposals in Table 18 span across the hierarchy of the network, a specific segment on coordination is evident.
5) Both Table 17 and Table 18 propose alterations to the wholesale market, those in the former are to increase economic efficiencies among a thermal generation set, whereas proposals in the latter alter the wholesale market around VRE generation.

These proposals reconfigure their respective electricity market design utilising concepts which were not feasible during the previous decade. This evidences how the debate around market design co-evolves and reacts to technological advances, making the most of opportunities which present themselves.

Building upon Table 18, the solutions proposed within these papers offer several means to re-structure an electricity market design as summarised in Table 19. As demonstrated by Table 18, Table 19 and appendix three, there is a range of proposed reconfigurations to liberalised electricity market designs.

Table 19 Compiling the proposed re-configurations identified in the papers reviewed in Table 18 into their proposed location on the network and whether the proposed changes are regarding the need for coordination.

Distribution network:	**Transmission network:**	**Coordination:**	**System wide:**
Peer-to-Peer (Mihaylov et al. 2014; Riesz and Milligan 2015; Kristov et al. 2016; Parag and Sovacool 2016; Mengelkamp et al. 2017; Morstyn et al. 2018, 2020; Zhang et al. 2018, 2020a; Stanley et al. 2019) **Blockchain** (Mengelkamp et al. 2017; Morstyn et al. 2018; Borowski 2020) **Local balancing** (Mihaylov et al. 2014; Ilieva et al. 2016; Parag and Sovacool 2016; Mengelkamp et al. 2017; Roques and Finon 2017; Zhang et al. 2018) **Islanding the grid** (Riesz and Milligan 2015; Ilieva et al. 2016; Parag and Sovacool 2016; Mengelkamp et al. 2017; Peng and Poudineh 2017; Zhang et al. 2018) **Virtual Power Plants** (Parag and Sovacool 2016; Stanley et al. 2019; Xu 2019; Papalexopoulos et al. 2020) **Prosumers balance** (EcoGrid 2016; Papalexopoulos et al. 2020)	**Wholesale market**: • Permit DER to compete (Kristov et al. 2016; Papalexopoulos et al. 2020) • Shorter trading periods times (Mihaylov et al. 2014; Ilieva et al. 2016; Market4Res 2016; Neuhoff et al. 2016; De Wit 2017; Mengelkamp et al. 2017; Joos and Staffell 2018; Xu 2019) • Gate closure as close to real time as possible (Market4Res 2016; Mengelkamp et al. 2017) • Split into two markets (Keay and Robinson 2017; Pierpont and Nelson 2017) • Exclusion of day-ahead, intraday and balancing mechanism (De Wit 2017) • Shorter trading periods (Joos and Staffell 2018) • Shorter gate closure (Joos and Staffell 2018)	**Aggregators:** • Pool prosumer flexibility to Transmission System Operator (TSO) (EcoGrid 2016) • Pool DER into wholesale market (Kristov et al. 2016) **TSO**: • Dispatches DER (Kristov et al. 2016; Gerard et al. 2018) **DSO**: • Coordinate DER within their system (Kristov et al. 2016) • Aggregates DER and bids this into the wholesale market (Kristov et al. 2016) • Facilitate balancing at the local level (Roques and Finon 2017) • Solve distribution grid issues then offers remaining flex to TSO	**VRE as balancing responsible parties** (Ilieva et al. 2016; Peng and Poudineh 2017; Roques and Finon 2017) **Priority dispatch for VRE** (Market4Res 2016) **Award long term contracts via auctions** (Roques and Finon 2017) • for VRE via auctions (Keay and Robinson 2017; Peng and Poudineh 2017) • new generators, storage and Tx DSR (Gimon 2017) **Carbon price** (De Wit 2017; Newbery 2017) **Smart energy system approach** (Lund et al. 2016; Sorknæs et al. 2020)

Platforms: • Procure grid services (Papalexopoulos et al. 2020) • Procure prosumer flexibility (EcoGrid 2016; Stanley et al. 2019) • To trade locally produced generation (Ilieva et al. 2016; Parag and Sovacool 2016; Mengelkamp et al. 2017; Morstyn et al. 2018, 2020; Zhang et al. 2018) • Facilitate trade between power plants and consumers via this platform (Bielen et al. 2017) **Aggregators** • Local Market Operator (Rosell et al. 2018) • Oversees flexibility transactions in the local energy community (Rosell et al. 2018) • Pools flexibility (Esmat et al. 2018) • Compete with other aggregators for flexibility to the DSO (Morstyn et al. 2018) • Operates platform to procure local flexibility **Local markets** • **Ancillary** (Hogan et al. 2016; Roques and Finon 2017; Gerard	• Nodal pricing policy (Hogan et al. 2016; Newbery 2017; Peng and Poudineh 2017; Roques and Finon 2017; De Vries and Verzijlbergh 2018; Borowski 2020; Bichler and Buhl 2021) • Zonal pricing policy (Market4Res 2016; Neuhoff et al. 2016; Peng and Poudineh 2017; Roques and Finon 2017; Energy Systems Catapult 2019, 2021) **Flexibility markets** (Bichler and Buhl 2021) **Balancing mechanism:** • Technologically neutral balancing mechanism (Market4Res 2016) • Open up balancing mechanism to VRE (Joos and Staffell 2018)	(Gerard et al. 2018; Rosell et al. 2018) • Negotiates directly with each prosumer (Morstyn et al. 2018) • May operate a local energy market (Papalexopoulos et al. 2020) • Operates a flexibility market to solve congestion issues (Esmat et al. 2018; Morstyn et al. 2018) **Local markets** • Trades into the wholesale market (Ilieva et al. 2016) **Shared markets** • Flexibility market for both DSO and TSO (Ashouri et al. 2017; Gerard et al. 2018) • Markets located behind the meter (BTM), Distribution and transmission (Papalexopoulos et al. 2020)	**Reform the CfD** (Cornwall Insight 2020a; Policy Exchange 2020a) **Reform the capacity market** (Policy Exchange 2020a)

et al. 2018; Morstyn et al. 2018; Rosell et al. 2018; Zhang et al. 2020a) • **Local flexibility market** (Esmat et al. 2018; Rosell et al. 2018) **DSO SPOT market** (Hogan et al. 2016) **Nodal pricing policy** (on the distribution network[1]) (Hogan et al. 2016; De Vries and Verzijlbergh 2018; Liu et al. 2018; Morstyn et al. 2020; Policy Exchange 2020a; Savelli and Morstyn 2020) • At the Grid Supply Point (GSP) (Kristov et al. 2016) • At all levels of the distribution network (Papalexopoulos et al. 2020)			

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[1] Also known as distribution locational marginal pricing (DLMP)

5.3.1 Reasons for this recent interest in electricity market design

In reviewing the literature, three possible reasons can be identified behind this surge in publications on the topic of electricity market designs.

First, and as highlighted within the literature review, the electricity market design is fundamental to the economics of the electricity system, dictating where the value flows are who has access to revenue; this is in itself a justification for study into this topic. In addition, the interest appears to stem from the realisation that the electricity market design is inappropriate for emerging actors and technologies and, in this sense, is no longer fit for purpose with value flows largely reflecting a 20th century electricity system; sections 5.1-5.3 discussed a number of instances in which this is the case and how these issues can be addressed. Furthermore, the transformation of the electricity sector brings a range of opportunities (e.g. utilising flexibility from the demand side) which appear to elicit an interest from the wider academic and industry community.

Second, the need to reconfigure the electricity market design is increasingly recognised as a requirement to achieve a net zero electricity system and this is reflected in academic research activity in this area. For example, projects exploring the reconfiguration of the electricity market design such as the Horizon 2020 P2P Smart Test and the EPSRC Mistral project were awarded €3.8million and £5.3million respectively (European Commission 2015; EPSRC 2016). In parallel, the interest in market designs is reflected in academic journals publishing special issues in this area, such as the *Energies*' 'Market Design for a High-Renewables Electricity System' (Energies 2020) and *The Institution of Engineering and Technology* put out a special issue on Demand Side Management and Market Design for Renewable Energy Support and Integration (IET 2018). Industry publications are also following suit, with recent proposals from the Energy System Catapult (Energy Systems Catapult 2021) and the Policy Exchange (2020a).

Third, the opportunities which stem from the reconfiguration of the electricity market design are being realised through real-world trials, and research is needed to support market redesign. Trials such as Centrica's LEM (2018), Oxford's project LEO

(Oxford City Council 2019) and EcoGrid.EU (EcoGrid 2016) are providing case studies for new means of operating the electricity market design. Benefits from these trials include the balancing of local demand with local supply, making flexibility increasingly visible and providing a value for the service and balancing an increasingly fluctuating grid via demand-shifting using home-automation technologies. Yet, there is need to be cautious of deploying private platforms which are unregulated. Bray et al. (2020) argued that Ofgem will need to consider how network charging would incentivise for consumer behaviour. The same should also be said for the private platforms themselves, which could arguably 'cherry-pick' value from their consumer base, and pass on associated costs to the end consumers (Willis et al. 2019a).

5.3.1.1 The scale of proposed re-design identified within the literature

The 49 reviewed designs differ in the degree of change they propose. This degree of change can be observed in the number of cells which have been colour coded for a particular design in the Excel spreadsheet in appendix three according to the key described in section 5.3.

Many of the proposed designs are limited to what could be considered ‘minor’ alterations to their respective electricity market design – such as the implementation of peer-to-peer trading (Parag and Sovacool 2016; Zhang et al. 2020a) and the introduction of decentralised marketplaces for the procurement of flexibility as a service (Esmat et al. 2018; Morstyn et al. 2018). There are then proposals which introduce a more substantial change, inasmuch as they would significantly augment the current electricity market design – such as the shift from the current uniform pricing policy to the introduction of nodal pricing (Pierpont and Nelson 2017), and taking this even further with nodal pricing located on the distribution network (Hogan et al. 2016; Kristov et al. 2016; Policy Exchange 2020a).

There are also designs which call for more than just a single change, introducing a wide range of reforms within their proposed design. For example, Energy System Catapult’s (2021) proposal calls for the investigation into nodal/zonal pricing, reducing timescales for trading periods, implementing local platforms for the trade of electricity and services, the introduction of local flexibility markets, strategic reserve combined with decentralised reliability options as a replacement for the capacity market, and the phasing out of the CfD.

In this sense, there is no consensus in the literature about the scale of change required, rather proposed re-designs vary depending on the objectives of each author.

5.3.1.2 The scale of proposed re-design identified by interviewees

The scale of electricity market re-design ranges from layering incremental changes, such as code modifications, to major displacement events, such as NETA. Reviewing the themes which have emerged from interviewees, it is clear that here too there is no consensus on the scale of alterations required to the electricity market design.

On the topic of the scale of market re-design required, analysis of the interview data revealed two distinct schools of thought. The first school prefers layering[1] change onto the existing system: proponents consider that a substantial element of the current electricity market design continues to provide a beneficial service and should be retained, but recognise that some minor alterations are required to increase the overall efficacy of the electricity market design. The second school of thought espouses 'displacement': advocates observe that the fundamentals of the electricity market design in question is no longer fit for purpose, and argue that many modules need to be reformed. Consider the wholesale market as an example: this module was seen by an Ofgem representative, an SSE renewables representative and an Energy Consultant (Interview 3, 7, 23) as a useful and effective element for the dispatch of generation within the electricity market, but they accepted that it is falling short with regard to securing new forms of investment in low carbon generation. In an attempt to resolve this, Interviewee 7 proposes the implementation of an additional mechanism, layered on top of the existing wholesale market, known as an Energy Floor Price Model (EFPM) which would effectively adjust the current CfD regime (Cornwall Insight 2020a). On the

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[1] The function of 'layering' has two purposes within this thesis. The first is within chapter three in the process of creating the strawperson design and is referred to as a means to add new rules onto an existing module. In this context, layering is one of three means of creating the proposed strawperson design, used alongside exclusion and augmentation. The second use is within the context of theorising institutional change, as a means of adding on new rules to the existing institution as opposed to displacement which is the replacement of the existing rules.

other hand, Interviewees 11-12 suggest a fundamental restructuring of the wholesale market through splitting this module into two (more details on these proposal can be found in appendix six, section four and nine respectively). Other, smaller scale alterations were supported. For example, the continued deployment of local energy markets such as the Cornwall LEM (Interview 6, 9). Both of those who supported the LEM have a vested interested in the success of this venture.

- A representative of the C-LEM: There is a clear vested interest for the success and further deployment of the LEM as this company have invested piloting the concept and now have experience of operating this market. They can see this as a future means to secure revenue from an increasingly decentralised network (Interview 9).
- A representative of the ENA: World E of the ENA's Future World work package is underpinned by flexibility being procured via independent platforms such as the LEM (Interview 6) and therefore support the inclusion of this (ENA 2018). Therefore, there is a key role for the LEM in the ENA's vision and thus there is an interest in the success of such a third party operated platform.

It is of note that there is a discernible relationship between whether a respondent indicated a preference for layering as opposed to displacement approach to change and their degree of vested interest in GB's electricity market design. Those who favoured layering changes could generally be considered to have stronger vested interests: they represented organisations with established revenue streams in the current system. These organisations would benefit from the introduction of an additional element without removing the existing source of revenue, for example, such actors supported the amendment of an aspect of the wholesale market which would not influence their current business model. Conversely, those proposing a displacement approach to change had less vested interest; generally, those representing organisations without existing revenue streams linked to the functioning of this institution indicated a willingness to propose more dramatic changes.

This too offers a point of reflexivity of the researcher who does not depend upon the current revenue streams of GB's electricity market design and is not bound by these considerations of impacts but rather is distant and can therefore consider the optimal design.

5.4 Chapter conclusion

This chapter has identified issues with GB's existing electricity market design based on both a literature review and interviews with experts, justifying the need to implement an electricity market re-design. Building upon this, alternative electricity market designs were introduced, along with an explanation for the increased interest in redesigning the electricity market and the potential scale of change.

These proposals lay the foundations of the electricity market design which was created following the methodology presented in chapter four; this design shall be introduced in chapter six.

6.0 The thesis's proposed electricity market design

Chapter four detailed the methodological approach to create a strawperson electricity market design for GB and how this was appraised, validated and refined. This chapter will introduce the thesis's proposed design and discuss how this is a 'fit for purpose' design based on facilitating the objectives and goals stated in chapter four and how this design addresses the issues identified in chapter five. The proposed design reflects an augmentation of the current electricity market design within GB.

In re-designing each module several possible alternative reconfigurations could have been incorporated, leading to 'trade-off' decisions by the researcher needing to be made. Appendix six provides an in-depth explanation, discussion and justification of these decisions; this appendix is intended to be read alongside this chapter. Within this appendix, consideration is given to how the options selected meet the goals for the fit for purpose design whilst resolving the issues identified in chapter five.

The following section presents the proposed electricity market design of this thesis for GB. The proposed electricity market design for GB has been published in the journal *Energies* (Pownall et al. 2021). Appendix seven provides a copy of the published article.

6.1 The proposed electricity market design

The proposed electricity market design consists of seven interrelated modules:

- Module one: The DSP Pool market
- Module two: The DSP ancillary market
- Module three: The DSP balancing mechanism
- Module four: The wholesale market
- Module five: The independent integrated system operator (IISO) ancillary market
- Module six: The IISO balancing mechanism
- Module seven: Capacity remuneration mechanism (CRM)

Figure 34 provides an illustration of the location of each of these proposed modules on the network and the possible trade routes. These trade routes also highlight the possible value flows stemming from the distribution network into the wholesale and

IISO markets. These modules operate in parallel, with actions taken within one module impacting upon another. This clearly underscores the requirement for coordination between these market modules and the organisations which govern them. It is therefore essential that there are clear, established routes for coordination between modules to avoid conflicting actions being taken. The following section will delve into the purpose of each of these modules independently before detailing how these modules shall be coordinated in section 6.1.7.

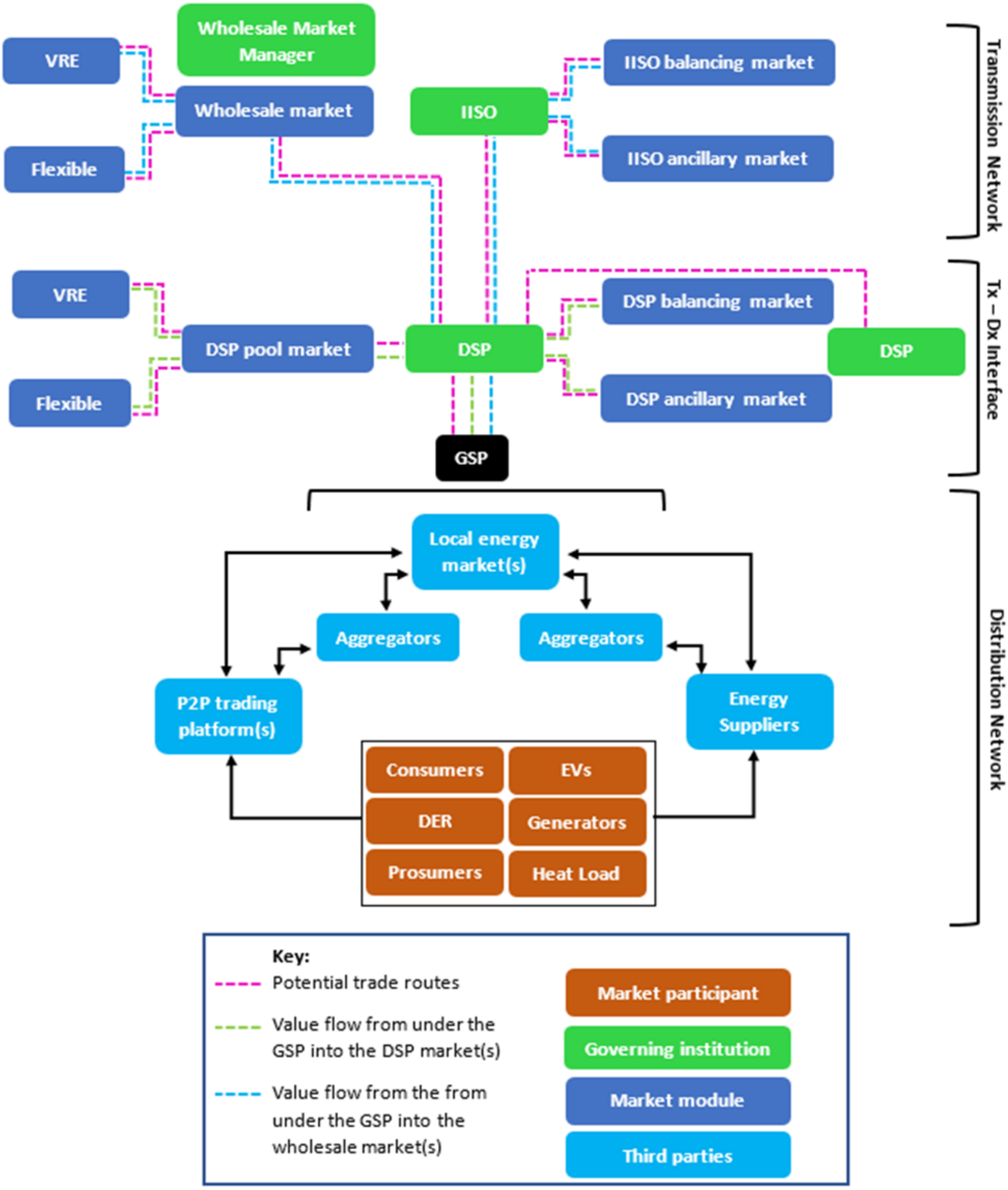

Figure 34 Schematic of the proposed electricity market design with potential trade routes, value from the GSP into the DSP, IISO and wholesale market identified. Only one GSP for illustrative clarity. In reality, there would be multiple GSPs within a DSP's geographical remit.

6.1.1 The wider institutional framework

The proposed electricity market design for GB has been integrated into the IGov institutional framework (Willis et al. 2019a). Whilst the proposed electricity market design can exist outside this framework, by integrating it situates the electricity market design among organisations with new rights and responsibilities allowing for the design to work as intended. This section provides an overview of these organisations and is a precursor to sections 6.1.3-6.1.5 which details these in more depth in relation to their function within the proposed design.

The Distributed Service Provider (DSP):

Inspired by the New York State's 'Reforming the Energy Vision' and IGov, in this thesis the DSP is an evolution of the current DNO structure operating within GB. It combines the existing functions of the management of networks with system operations and the role of facilitating local balancing and coordinating via their own marketplaces. This agent would develop markets for energy services, as opposed to the current metric of units of electricity, through the procurement of both electricity and ancillary services such as flexibility. In doing so the DSP will deliver a public good through communicating revenue opportunities via the transparent clearing prices of these marketplaces for generators and service providers within their geographical remit whose actions would aid in increasing the resilience of the network.

Within GB the DNO is currently under a transition to a DSO, and the proposed design introduced within this chapter refers to the DSP. The roles and responsibilities of each organisation differs, yet it is easy to confuse these organisations with one another. As such, Table 20 clarifies the roles of these three organisations.

Table 20 A summary of the DNO, DSO and DSP with key attributes. Note that the role of the DSO within GB is still under discussion and therefore specific details remain unknown. Information sourced from (ENA 2015, 2021b; Mitchell 2016b, 2017b; Mitchell and Poulter 2018).

	DNO	DSO	DSP
Summary	Business as usual. Facilitates the supply of energy units to consumers, maintains operational standards with incentives from making a rate of return on capital assets. This favours the deployment of new assets rather than exploring non-wire alternatives.	A more active version of the DNO, but retains elements of the business as usual regime. The DSO will investigate the implementation of some non-wire alternatives but the extent to which these are financially incentivised over the deployment of new infrastructure is not yet certain. The DSO is posed to procure ancillary services through mediums such as third-party private platforms e.g. PicloFlex (Piclo 2018). These services may be offered to the transmission system operator as well.	The DSP is the most active of the three bringing new roles forward such as the area coordination of energy and system services, market facilitator and balancing at the distribution-transmission network interface, known as the grid supply point (GSP). This is facilitated by how the DSP is incentivised[1].
Balance their network?[2]	No.	No.	Yes.

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[1] For more details on the proposed incentive structure visit (Mitchell 2017b).

[2] Within this context balancing refers to the matching of supply and demand, not frequency, which would be reserved for the IISO. This is in place as alterations of frequency are instantaneous, and would have an impact on the entire synchronised grid. Therefore, having several institutions (the DSPs) attempting to alter the frequency of the network could lead to a less stable grid and it is therefore better for this service to be procured by a single entity (the IISO).

Facilitate the trade of electricity?	Partially – under the flexible power program DNO’s are able to directly procure flexibility from those within their geographical remit to reduce known network constraints (Flexible Power 2021).	Partially – through tenders by private third parties.	Yes.
Coordinate assets and service providers?	No.	Limited – may coordinate assets within their region if the DSO has this within their licence.	Yes.
Coordinate dispatch with system operator?	No	May do, not yet determined.	Yes.
Prioritise non-wire alternatives over network reinforcement?	No.	Partially.	Yes.
Transparently reveal value on their network?	Partially – limited transparency is being revealed by private third parties such as PicloFlex’s free to accessing bidding data (PicloFlex 2020).	Unknown.	Yes.

The DSP will stimulate and incentivise the various functions required which cannot be brought forward via regulation alone. Under the proposed license conditions, the DSP would be required to balance its geographical region which retain the boundaries encompassed by the current DNOs. This is realised through the implementation and operation of the DSP pay-as-clear Pool market, the DSP ancillary market and DSP balancing mechanism for each of the GSP operated under the SPOT timescale within the DSP's region[1]. This is intended to result in the netting off of local geographical regions and facilitate an efficient use of the network in doing so, through utilising services providers close to where they are needed via their various marketplaces.

Despite the growth in decentralised activity within GB's electricity sector, GB's wider electricity governance framework remains highly centralised and largely operational only at the national level. The DSP would be fundamental to the shift from the current linear, top-down value chain to one where consumers are central and provides value for efficiency, flexibility and sustainability. Through operating marketplaces at the GSP the DSP would contribute to providing clear signals which show the energy economics at the distribution level of the network, addressing the distribution gap identified in chapter five, section 5.1.6. This would differ to today in which the economics of this system are determined by centralised and often fossil fuel units, with the small-scale units valued through the retail market, i.e. via a centrally determined FiT.

The DSP will stimulate competition within their regions via these marketplaces and indeed may result in the creation of new private local marketplaces operated by third parties to fulfil the services required of the DSP; such as the present case between PicloFlex providing grid flexibility to DNOs today (Piclo 2018). As there will be clear routes to markets and transparency in the prices paid for power and services, the DSP should stimulate investments into the deployment of local capacity and service

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[1] The geographical boundaries encompassed by a DSP would reflect that of the DNO. As such, a DSP regional may have several GSP regions within their geographical remit.

providers required to satisfy the DSP's requirements. This in turn will indicate to potential investors where a RoI could be feasible.

IGov propose the implementation of local transformation plans which would see devolved responsibility to local authorities (Willis et al. 2019a). These local transformation plans would be promoted by the DSP who would coordinate with the wider policies introduced via these local transformation plans. Through the stimulation of local resources within their region energy efficiency is supported. For example, by incentivising local generation/demand being used to meet load requirements rather than requiring generation to flow vast distances across the transmission network which may result in constraints and would enable an improved use of the network. In this, GB's electricity market design and network regulation must therefore complement each other to aid in the facilitation of a net zero power sector. Further considerations on network regulation is provided in section 6.1.2.2.

The functions of this institution in relation to market operation will be discussed within section 6.1.3. Defining what the role of this institution has been sourced from various literatures, but most heavily from IGov's work as mentioned above and from the review of the 49 papers with proposals for electricity market reform. It is the latter which has evidenced the need for specific roles to be conducted by the DSP. Referring to Table 19 there are several proposed re-configurations located on the distribution network which the DSP can perform. These include the role of local balancing, local ancillary/flexibility markets and bringing forward a nodal pricing policy. Each of these has been incorporated into the remit for the DSP. These decision include trade-offs, which are discussed throughout Appendix six; for example, whether to have a local ancillary market operated by each of the DSP's or retain the current method of having a single ancillary market operated by the IISO.

The Independent Integrated System Operator (IISO):

The IISO is an evolution of National Grid ESO and is conceived as an independent and non-profit system operator who oversees the electricity, heat and transport sectors at both the transmission and distribution levels, with the DSP being responsible for balancing and coordination on the distribution network (Willis et al. 2019a, 2019b). The specific remit of the IISO in relation to this electricity market design is principally to ensure that the entire grid is constantly in balance, a continuation of this responsibility from its predecessor. The IISO facilitates this through operating the IISO ancillary and IISO balancing mechanism as will be introduced in section 6.1.5.

The IISO would also absorb the function of code manager. This would bring together the several different code bodies into one easy-to-access space which is transparent, accessible and fair to all market participants wanting to enact change (Willis et al. 2019a). This proposal shares similarities with BEIS and Ofgem's proposed 'model two' for the future of code governance, with the introduction of a single organisation known as the integrated rule making body (BEIS and Ofgem 2019). The IISO taking on the role of code manager represents a shift away from current code governance which is not representative of a system trying to bring forward innovation and change.

Wholesale market manager:

The wholesale market manager would be responsible for the efficient operation of the wholesale market through the coordination of the renewable and flexibility market – a two-tier markets structure which will be introduced in sections 6.1.3.1 and 6.1.4. The DSP will perform the function of facilitating the two-tier market structure for each of their GSPs.

Wholesale market monitor:

It is essential that the various marketplaces proposed within this design operate efficiently and that no market manipulation occurs at the expense of the end consumer. The wholesale market monitor is proposed to oversee trades to ensure that the markets are operating as intended. This would be achieved through the incorporation of Ofgem's REMIT function alongside the market monitoring services provided by Elexon.

The wholesale market monitor would coordinate with the wholesale market manager to access data from trades in the SPOT market to identify signs of market manipulation. To ensure the standardisation of practises the wholesale market monitor would liaise with the DSP entities who monitor the trades within their geographical regions.

With this overview of the entire electricity system, the wholesale market monitor will ensure that trades across the electricity system are fair and transparent - as well as acting as a deterrent against market abuse through heavy fines.

6.1.2 Proposed Regulatory changes

This section briefly summarises two regulatory changes which are proposed alongside GB's electricity market design to allow the design to operate as intended. Regulation within the electricity sector influences both the operational decisions of service providers and influences the investor confidence for deploying new assets onto the network (Market4Res 2016; National Grid ESO 2020m). As such, appropriate regulation must be aligned with the electricity market design. The two proposed changes are 1) for VRE to have priority dispatch alongside 2) alterations to network charges to account for the distance of network utilised in trades.

6.1.2.1 Priority dispatch for VRE

Priority dispatch, the obligation for the system operator to dispatch VRE before their thermal counterparties is placed on the IISO, DSPs and the wholesale market manager. This is realised through the first market tier, the VRE market which intends to meet initial demand before calling upon addition flexibility as required via the second tier. VRE will typically be dispatched first due to their near zero marginal costs; yet, priority dispatch provides further reassurances to investors that their VRE generating assets will be utilised (Bauknecht et al. 2013; Market4Res 2016).

6.1.2.2 Network charges

A re-design of GB's network regulation is outside the scope of this thesis. Yet, this section offers a suggested changes which can aid in providing the locational signals required under an increasingly decentralised electricity sector whilst complementing the intended practices brought forward within the proposed electricity market design.

Ofgem (2019f) revised network charging to implement a fixed charging approach for households and businesses which is arguably a continuation of the centralised, top-down approach which considers consumers to be passive. A more efficient use of network charging can be facilitated through a more reflective pricing policy which the DSP can contribute to. As the GSP is the interface between the distribution and transmission network, all assets located within the GSP region are situated on the distribution network, and therefore all trades occurring within the GSP would only incur distribution network costs. This is to provide a financial incentive to encourage trades within the GSP; Leading to the associated benefits of balancing locally, reducing constraints, increasing liquidity within a GSP and facilitating the price discovery for specific resource providers within a given geographical region (See chapter five, section 5.1.6). Furthermore, when a trade requires the use of both the distribution and transmission network the parties in question would have to pay for both the distribution and transmission network charge. This price difference may dissuade the practice of trading over large geographical distances, freeing up capacity on the network. However, at times the financial return from a long-distance trade may outweigh the additional network charges. The specifics of such a reform are outside the scope of this thesis, but the principle aim would be for network charging to incentivise efficient use of the network in a manner which would incentivise the netting off of each GSP.

6.1.3 The DSP

Modules 1–3 are introduced to facilitate the local balancing and coordinating market at each GSP within a DSP's geographical region.

6.1.3.1 Module one: The DSP pay-as-clear Pool

This proposed augmentation introduces a Pool market settled by an auction based upon the pay-as-clear principle. Each of these pay-as-clear Pool markets is located at the GSP, and consequently a single DSP may govern several of these markets. The rationale for these decisions are detailed in appendix six, section three.

A Pool market was selected due to its suitability for VRE generating assets as detailed in Table 21 – it has characteristics which are beneficial to smaller market participants likely be entering the DSP market. An auction was selected over continuous trading as the clearing mechanism due to favouring smaller market participants (See appendix six, section five). This stems from the standardisation of contracts and the predetermined trading times, which in theory should reduce the burden of expertise and constant monitoring of the market compared to continuous trading (Lin and Magnago 2017; European Commission 2019b).

Liquidity within each of the DSP pay-as-clear Pool market may be a concern due to a reduction in the geographical network, and by proxy a reduction in the number of market participants. Yet, the adoption of an SES approach, introduced in chapter five, section 5.1.6 should increase the number of participants within the GSP as many of the electrified technologies, including heat pumps and EVs, will be connected beneath a GSP on the distribution network who can trade into these various marketplaces.

Table 21 The rationale for selecting a Pool market as opposed to only self-dispatching. Source: (Mitchell 2015; Riesz and Milligan 2015; Lin and Magnago 2017; Mengelkamp et al. 2017; Roques and Finon 2017; EPEXSPOT 2020).

	Pool
Suitability for VRE	Reduced risk of facing imbalance charges as a result of a central market which pools liquidity. This promotes the ability for VRE generators to procure, or sell, depending upon the environmental conditions which may result in deviations from contracted positions.
	Due to standardised products, trades can operate on a faster timescale allowing them to occur closer to real time compared to continuous trading. This also allows VRE to react to fluctuations in output due to environmental conditions and mitigate imbalance charges.
Transparency	Uniform price auction provides transparency and ensures that the least expensive and most efficient generating unit or service is dispatched.
	Market prices are visible to buyers/traders/sellers.
Reducing trading costs	Typically lower transaction costs than continuous trading.
	Safe counterparty risk, often provided by the central exchange, though credit cover will need to be lodged so this route is not without cost.

Each of these DSP pay-as-clear Pool markets would operate under a two-tier market structure. The first tier is for VRE generating assets, whilst the second is for the procurement of flexibility.

Auctions held at both the DAH and ID timescale will signal to the DSP the forecasted output of VRE generating assets (due to priority dispatch) along with forecasted demand at the GSP. Any shortfalls of VRE output compared to demand are then met by the flexibility market which opens once the result of initial auction of the VRE tier is known. This second tier is dedicated to the procurement of flexibility from the electricity, heat and mobility sectors. If the flexibility market clears at a higher price than the clearing price for the initial VRE auction, this would raise the overall clearing price within the GSP for that settlement period. All technologies and resource providers are permitted to enter into the flexibility market, but the application of a carbon-based tax will improve the viability of deploying non-thermal flexibility assets such as DSR. The DSP as the operator of this marketplace would then send dispatch instructions.

The DSP will hold regular auctions to determine the clearing price and will subsequently dispatch those who are in merit. The clearing price at each GSP pay-as-clear Pool market will differ based upon a range of factors including the technologies present within that node, the environmental conditions dictating VRE output, the level of demand needing to be satisfied within the region and the short run marginal costs of those competing within the flexibility market. As such, this will aid in reflecting the true energy economics in which prices for either power or flexibility will be based upon the local geographies with these prices themselves reacting to capacity entering or exiting a GSP region. This is reflective of a nodal pricing policy(For more details, see appendix six, section one).

There are several means for the DSP to secure the required service within their geographical region; be that from their own GSP regions or look towards securing from other DSP regions of the wholesale market itself. The decision on where to secure from will be made on a case-by-case basis. For example, when a DSP can locally balance at low cost and low carbon then these trades would be utilised, rather than procuring from alternative marketplaces which will also need to factor in the increased cost of using networks (a proposed network charges introduced in Section 6.1.2.2).

In a scenario where a DSP is unable to satisfy their needs locally, or to do so would be more expensive than an alternative, including the associated network charges, the DSP would be able to procure from a variety of alternative marketplaces. This includes options such as bidding into to the markets of another GSP within their remit, a different DSP or from the wholesale market. If the price to procure the service is higher than the original GSPs pool price, then this will rise to meet the cost of this external procurement. This in turn will provide a short-term investment signal for service providers able to offer flexibility to the network within that region.

They would do so through the submission of a bid into these other marketplaces. At times when the clearing price in the alternative marketplaces is higher than the initial GSPs, this will increase the clearing price in the importing region. Contracting with another DSP region or the wholesale market will harmonise the prices between these two geographical regions. Transmission connected technologies are not permitted directly to enter into the DSP pay-as-clear Pool market. However, their services may be indirectly procured if the DSP buys a specific service from the wholesale market, or the IISO's ancillary and balancing mechanism. Nevertheless, during times when there are constraints between the two regions such trades would not be possible to facilitate. Instead, the required service would need to be met by a generator or service provider who is not impacted by the constraint. As such, two regions under a constrained network would have two different prices for the same service due to the reliance of different generators and/or service providers with their different SRMC to cover. This is also reflective of a nodal pricing policy.

As such, the clearing price of GSP Pool market may different to another marketplace if 1) if a GSP region is able to net itself off without requiring additional capacity from another GSP, DSP or wholesale market and 2) there are constraints on the network which do not permit the harmonisation of prices between two regions.

In regards to the operations within module one, market participants such as those highlighted in Table 22 have a variety of marketplaces to enter, from private third party platforms within their GSP region, the GSP pay-as-clear Pool, the DSP's ancillary market and balancing mechanism. In principle, there are no restrictions on who can trade with whom (Figure 34).

In addition to the aforementioned trading routes, market participants are permitted to enter into bilateral contractual agreements with fellow market participants located within their node or across the network. Such contracts would likely reflect the CfDs which were popular at the time of the Pool in England and Wales post privatisation. In this manner, the contractual agreements will be based upon the respective Pools clearing price with the difference being paid out accordingly. For example, two parties may agree to enter into a CfD with each other for £50/MWh, if the clearing price of the respective Pool market is higher or lower than this strike price the difference will be paid out. This provides a means for both parties to hedge against a volatile clearing price. Clarity on how the DSP would assess this trade off may stem from adequate regulation of this organisation. IGov’s work on the DSP takes heavy influence from the New York REV, which introduced performance-based regulation for their regulated entities[1]. This placed financial incentives on these regulated organisations to meet a certain objective. These performance-based objectives could reflect carbon intensity of trades, the location of assets being dispatched and the cost of the action itself. This in turn would provide financially driven guidance to the DSP on how to meet their objective of netting off their region. The nuances of this regulation merit future research.

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[1] More Information on the NY REV and IGov’s commentary can be found in Willis et al (2019b).

Table 22 New and existing bodies that the DSP will coordinate with and the role they will likely play in the proposed electricity market design. This is not an exhaustive list as new and innovative business models may emerge in response technological changes, requirements of the DSP and the continued opportunities brought forward by the continued digitalisation of the electricity sector.

Body	**Description**	**Role within the proposed electricity market design**
Local Energy Platforms	These privately owned platforms contract with resource providers located in the GSP region. Such platforms are already emerging within GB, such as Centrica's LEM (Bray et al. 2018).	Offer resource providers access to revenue streams through a platform located in the distribution area. This may be for services such as power, flexibility and other ancillary requirements.
P2P trading platform	A means by which two parties can trade with each other either directly, or through an online platform, rather than going through conventional trade routes. Such platforms are already emerging within GB e.g. Piclo (Piclo 2016).	To facilitate trade between resource providers and consumers located within the GSP. This will provide the means for an intrinsic value for energy services as has been shown by the initial results of the Piclo Trial in which members paid more for their electricity when it was supporting a local generator (Piclo 2016). Data on trades would be sent to the DSP to ensure optimal power flow on their networks.
Aggregator	Aggregators such as LimeJump take separate assets and pool them together to represent one 'larger' asset (Limejump 2021). Their aggregated size provides access to market modules with larger clip size entry requirements.	To facilitate trade by utilising smaller resource providers and entering into market modules with a specific entry requirement. For example, an aggregator in a Sub-GSP region could combine together specific assets into a portfolio which could go into the DSP ancillary market.
Energy Supplier	Procures electricity on behalf of their customer base.	There may be an additional role for the traditional supplier as the GB energy system becomes increasingly decentralised and

		consumer orientated. One role could be the aggregation for resource providers. These entities are well placed to facilitate such a service due to their expertise in how the market operates, understanding of how to provide specific services and already having an existing relationship with the end consumer.
Resource Provider	The resource provider is an entity which offers their services, including supply, demand-side management techniques, storage or any other system service.	To provide a service, trading directly into the market modules themselves, or, via one of the private third-party platforms listed within this table.
Future developments	With technological advancements and new requirements of the grid, there will be evolutions of existing bodies alongside the emergence of new ones to fulfil new roles. Therefore, innovations will occur and must be incorporated when technically and commercially feasible.	

Relevant data on all trades facilitated within the GSP, into the DSP pay-as-clear Pool market, bilaterally between market participants or into the wholesale market, will be publicly available, with confidential data being omitted/anonymised. The precedent for this practice is evidenced by PicloFlex, a private third-party operated marketplace for the tendering of flexibility for DNOs within GB. Their platform facilitates free access to a wide range of competition and bidding data, detailing the availability and utilisation fee, the capacity offered, the time of activation and an indication of where on the network the successful assets are located (PicloFlex 2020).

This transparency will generate substantial volumes of data revealing the value received from the performing of a specific action, e.g., providing flexibility and how this compares to other regions on the network. Such detailed information would enable a project manager to analyse the RoI from a specific technology or provision of a service in a certain area on the network.

Considerations have been made to ease the entry requirements of smaller, less experienced market participants likely to be operating within the GSP, e.g., the implementation of auctions over continuous trading. However, time and resources may still pose barriers to entry into these marketplaces. It is envisaged that these obstacles will be eliminated as the provision of these services can be automated through the combination of artificial intelligence, internet-enabled technologies and novel private third-party businesses (who can provide this service whilst extracting value for both themselves and the end users (Strielkowski et al. 2019; Xu et al. 2019b)). As discussed within this section, there will be local private platforms operating within the proposed electricity market design. As such, there will need to be the appropriate regulations to ensure that they do not cherry pick value from their consumers and incur additional costs for end consumers in doing so (Willis et al. 2019a, 2019b). Furthermore, the transparency of the marketplaces operated by the DSP would identify agents who have incurred network costs, and attribute these accordingly.

6.1.3.2 Module two: The DSP ancillary market

The deployment of geographically distributed technologies in conjunction with development in IoT provides the means to solve localised grid issues with local service providers to the benefit of both the DSP and the IISO. The feasibility is exemplified by existing projects such as UKPNs' Power Potential in which this DNO utilises DER to resolve transmission voltage and thermal constraints through the increased coordination between UKPN and National Grid ESO (National Grid and UKPN 2017; National Grid ESO 2018a, 2020b). As such, each DSP will operate their own ancillary market at each of the GSP for the procurement of services via close to real time auctions. The rationale for this is provided in appendix six, section seven.

Furthermore, each DSP may need to procure bespoke services depending upon the characteristics of their network. For example, a DSP with high levels of onshore wind generation may need to procure additional reactive power to aid with localised grid stability. A discussion with a DSO manager at one of GB's DNOs (Interview 29) evidenced that there is already the need for specific products to deal with the unique characteristics of their networks.

At times, it may not be possible to source the required service to solve grid-specific issues from within the same GSP that the issue is located. Instead the DSP may need to call upon market participants from other GSPs within their region or procure from neighbouring DSPs or the IISO ancillary market. Determining when a DSP would instruct a fellow DSP to incentivise the deployment of an ancillary service from one of their market participant would be based upon an algorithm which would factor in aspects such as:

- Associated carbon
- The distance of the technology/service provider from fault
- Any network issues arising from such a dispatch
- The cost of procurement

This is not an exhaustive list, but rather outlines the key principles which should lay the foundations of these decisions. These criteria are underpinned by the facilitation of a net zero electricity system an efficient use of the network and the cost incurred by the end consumer. The nuances of such an algorithm are outside the scope of this thesis.

6.1.3.3 Module three: The DSP balancing mechanism

In addition to an ancillary market, the DSP will also operate a balancing mechanism for each of their GSP regions. The incorporation of a balancing mechanism operated by the DSP is introduced with the intention of netting off the energy demand of a GSP region with the supply from this same region (the rationale for this can be found in appendix six, section two). This is to promote the efficient use of the networks by reducing the total energy requirements drawn from across the network to provide balancing services and identify price signals to incentivise the deployment of a service provider. Market participants would provide bids and offers to the DSP stating the price they would require to either increase or decrease demand/generation. These are then cleared under an auction, based on a pay-as-clear mechanism (the rationale provided in appendix six, section five). At times, it may not be possible to balance a GSP with the technologies and service providers located within this geographically confined area of the network. Similarly to module two, an algorithm would also be designed to determine when the DSP would incentivise a market participant(s) from another GSP within the original DSP's remit, from another DSP region or the IISO's balancing mechanism to provide the required service via pricing signals.

6.1.4 Module four: The wholesale market

The wholesale market is operated by a dedicated wholesale market manager whose remit is to ensure transparency in prices whilst operating the two-tier market structure reflective of the DSP pay-as-clear Pool market. The standardisation of these two marketplace structures will support distributed technologies and services located within a GSP node into the wholesale market (ENA 2017; Shakoor et al. 2017). This route to market may be utilised if it is believed that there is a higher capture rate for trading into the wholesale market rather than their respective DSP pay-as-clear Pool market. In this scenario, the bids and offers made would be submitted to both the wholesale market manager and the DSP. The latter is informed of the trade to identify possible network concerns. Access into the wholesale market will be dependent on network constraints at the GSP, and the DSP can cancel bids and offers if they would cause network issues. Rationale for this set up is provided in appendix six, section four.

6.1.5 The IISO

Modules five and six are governed by the IISO. The specific remit of the IISO in relation to this electricity market design is principally to ensure that the entire grid is constantly in balance and frequency is maintained within the current technical boundaries pursued by the National Grid ESO, i.e. ± 0.5Hz of the targeted 50Hz. The IISO facilitates this through operating the IISO ancillary and IISO balancing mechanism (modules five and six).

The IISO will principally be reviewing the transmission-connected generation and demand, whilst the DSPs will satisfy the distribution network. With both IISO and DSPs licensed to provide balancing actions, clear routes of coordination between these two entities are required to ensure this task is completed efficiently e.g. no conflicting instructions are dispatched. These are detailed in section 6.1.7 and appendix six, section six and seven.

6.1.5.1 Module five: The IISO ancillary market

The IISO would be responsible for both national issues on the grid, such as overall grid frequency and for rectifying transmission network issues such as constraints. The products procured and their entry requirements will be standardised in common with the DSP ancillary markets to support access for market participants from the distribution network to this IISO market. In this case the DSP and IISO will need to coordinate actions.

6.1.5.2 Module six: The IISO balancing mechanism

The IISO will hold the obligation to maintain grid frequency within acceptable boundaries. The IISO will facilitate this through the operation of the IISO balancing mechanism, which will operate closer to real time than the DSP balancing mechanism. With balancing actions performed by both DSPs and the IISO, there is a need to coordinate the actions taken by each institution. This design proposes a two-step gate closure to support this, with the rationale for this decision located in appendix six, section six. Once the DSP has attempted to balance their geographical region their final physical notification (FPN) is provided to the IISO five minutes before real time. At this time, all transmission-connected generation/demand active within this particular settlement period would have also provided their FPN to the IISO via the wholesale market manager. The IISO will then have an overview of the entire distribution and transmission network with five minutes before real time, allowing the IISO to determine the balancing action required. This process is illustrated in Figure 35.

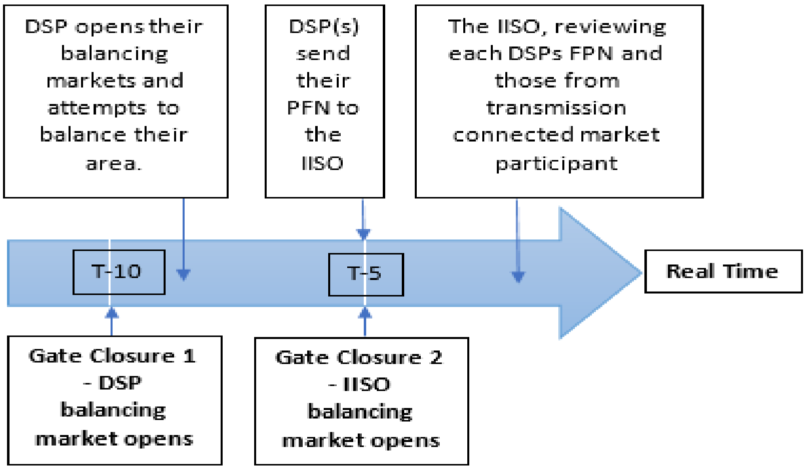

Figure 35 Proposed timeline of events illustrating the two-gate closure process.

Similarly to the wholesale market and the IISO ancillary market, the products will be standardised with the DSP's equivalent marketplaces to aid in the facilitation of technologies and services across the network.

The overview of the entire network will indicate to the IISO whether the culmination of imbalances from DSP regions, and deviations from the contracted positions of transmission-connected market participants may in fact 'net off' reducing the need for balancing actions. This would not be known by individual DSPs, further justifying the IISO receiving all FPN and implementing any remaining balancing actions.

6.1.5.3 Module seven: Capacity remuneration mechanisms

The current capacity market within GB is replaced with a combination of a strategic reserve (SR) alongside a Decentralised Reliability Option (DRO) scheme. Rationale for this can be found in appendix six, section eight. The SR provides the IISO with a reserve for times in which the market does not clear sufficient generation or demand shifting to meet the IISOs balancing obligation. The DRO provides a means for contractual agreements between those who can provide ‘reliability’ as a service such as a DSR unit or generating plant and those who require reliability such as a commercial business premise. This in turn allows the market to settle the level of reliability required by market participants, with the SR acting as the last resort only to be called upon in extreme circumstances.

6.1.6 Low carbon subsidies

As stated within Section 1.8, the boundary of this thesis does not encompass the long-term investment timescale. That said, this will be an area of interest for the reader and as such Appendix Six, Section Nine, details a review of several long-term investment options which could be implemented.

Under this thesis’s proposed electricity market design, there are opportunities to bring forward more locational, low carbon investment contracts through introducing contractual agreements which take the DSP into account. The subsection below introduces one of the reviewed contracts proposed in Appendix Six, Section Nine, to outline how this may work.

6.1.6.1 The energy floor price model (EFPM)

Proposed by Cornwall Insight (2020a), generators are guaranteed to receive at least the floor price for each MWh produced. A value is determined in a competitive tender in which bids for EFPM contracts are stacked in a merit order and cleared under a pay as clear mechanism. Winners will receive a guarantee for the MWhs they promised to produce.

The generator would receive a guaranteed floor price for each MWh they produce, similarly to the CfD they would be settled against the wholesale market and either receive a top up or pay-back to the counterparty which has provided the EFPM. When the price of electricity rises above the wholesale reference price, the recipient has to pay back to the EFPM until all previous EFPM top-ups had been repaid before they can capitalise on the higher wholesale price for electricity. The EFPM would ensure that market participants are expose to real-time pricing, and when prices rise above the floor the generator could lose out of revenues without also considering an investment in flexibility, such as storage. The costs of the EFPM would be recovered via consumers on a monthly fixed basis (£/kW). This mechanism could be built on top of the existing CfD arrangements.

This proposal could also be aligned to the wider changes proposed within chapter six. For example, in a discussion with the author of this paper the DSP could be the responsible organisation for issuing the EFPM in order to secure investment into specific needs within that region. The author suggested that the DSP could facilitate a regional auction for their specific needs (Interview 7). For example, if one region was short in capacity e.g. 100MW under its mandated target, the EFPM auction could be set up to procure this shortfall. Each DSP region could have a different clearing price to further incentivise locational differences.

6.1.7 Coordination

These seven modules are interrelated, and consequently the actions taken within one module could potentially impact upon another. Therefore, effective coordination between the governing institutions - the DSPs, the IISO and the wholesale market manager—is required to mitigate conflicting actions being taken. This relationship is compounded by the increasingly decentralised electricity system which requires the coordination of thousands of smaller units connected across the network and justifies a system operational role placed into the DSP's licence.

In relation to market participants from within a GSP entering into one of the national markets (modules 4–6), they would notify their respective DSP of the forecasted trade. This would allow the DSP to identify any network issues which may arise such as power flow, congestion and voltage deviations, and, if necessary, cancel the forecasted trade.

Furthermore, utilising distributed technologies to solve location-specific network issues will require efficient coordination between the IISO and the respective DSP to ensure cost-effective, safe and reliable use of these services. Options for the coordination between the DSP and the IISO are discussed within appendix six, section seven, which evidences the selection of a combined 'local ancillary service market model' with the 'shared balancing responsibility model' as proposed by (Gerard et al.

2018). In summary, the DSP would call upon technologies and service providers within their geographical region to solve local issues before sending any unused bids into the IISO’s ancillary market.

6.1.8 Summary of augmentations

In summary, there are several proposed augmentations, the specifics of each market module are outlined in Table 23 below.

Table 23 The modules, how they were augmented based upon concepts outlined in chapter four, section 4.5.2.6 and suggested specifics.

Module	Re-configuration	Specifics
The DSP Pool market	Augmented	Procurement method: Auction Timescale of procurement: DAH/ID Clip size: 0.05 MW Settlement: Pay as clear
The DSP ancillary market	Augmented	Procurement method: Auction Timescale of procurement: DAH/ID Settlement: Pay as clear Clip size: Product specific. No higher than 0.1 MW
The DSP balancing mechanism	Augmented	Procurement method: Utilising bids/offers Timescale of procurement: 5 min window before the opening of the IISO balancing mechanism Settlement: Pay as clear Clip size: 0.05 MW
The wholesale market	Layered	Procurement method: Auctions Timescale of procurement: DAH/ID Settlement: Pay as clear Clip size: 0.1 MW
The IISO ancillary market	Layered	Procurement method: Auctions Timescale of procurement: DAM/ID Settlement: Pay as clear Clip size: Product specific. No higher than 0.1 MW
The IISO balancing mechanism	Layered	Procurement method: Utilising bids/offers Timescale of procurement: Real time Settlement: Pay as clear Clip size: 0.1 MW
The capacity market	Excluded	Rationale for exclusion discussed in chapter two and five.
Strategic reserve	Augmented	Procurement method: Auction Timescale of procurement: Yearly auctions Settlement: Reserve price only paid during the contracted period of the SR. Clip size: 0.1MW
Decentralised reliability options	Augmented	Procurement method: Bilateral or auction Timescale of procurement: Bespoke Settlement: Settled against strike price Clip size: Bespoke

6.2 A discussion on how this proposed design meets the criteria of being 'fit for purpose'

This section shall justify how the proposed electricity market design proposed is 'fit for purpose'. This statement shall be evidenced and discussed in relation to the proposed design's theoretical ability to meet the intended objectives, goals and address the issues with GB's current electricity market design.

6.2.1 The 'purpose': assessing the proposed electricity market design against the key objectives

This section provides a discussion on how the four objectives of GB's electricity market design have been met. This section shall take each objective in turn.

Objective one: Efficient dispatch: Is the lowest cost resource being activated to meet demand?

With the proposed electricity market design based upon the principle of nodal pricing, the lowest cost resources within each node (each GSP), or within the wholesale market should be activated to either meet demand or shift it. One may argue that utilising generation/resource providers based upon geographical location, as opposed to just cost, may exclude the cheapest form of generation/demand if a cheaper technology/resource provider is located outside of the GSP. The current uniform pricing policy in GB assumes that the service from the cheapest form of generation/demand can always reach the intended area of the network, but this leads to high levels of constraint and curtailment costs. Referring to chapter five, section 5.1.3, which highlight that though wind generation from Scotland would be one of the cheapest and cleanest forms of generation to meet demand south of the border, the insufficient network capacity and flexibility has led to large levels of constrained wind generation resulting in the re-dispatch of a fossil fuelled counterpart south of the constraint[1]. This results in a higher cost to consumers as the wind generator, which likely receives an output-based subsidy, will expect to be paid to be constrained whilst socialised payments are also made to the fossil fuelled generator. Moving to the proposed design would reduce the cost of re-dispatch as only generation and flexibility within the locality of the GSP would be bidding in which would largely reflect network conditions and therefore would reduce the cost and potentially the carbon content of balancing the grid as well.

Objective two: Adequate capacity: Is there enough capacity to meet demand?

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[1] Whilst this may bring forward an argument to build additional network capacity to reduce the level of constraints, doing so through market mechanisms can reduce the need for costly reinforcements (As argued in chapter five, section 5.1.7).

The nodal style approach will provide locational signals for the deployment of generation and demand shifting services as prices within each region will reflect the local characteristics of the GSP. It is these local pricing signals which will indicate whether an area may require additional generation through high power prices within the node or flexibility opportunities presented via arbitrage opportunities. The move from the present uniform pricing policy where there is a single bidding zone to one which closely mirrors the nodal pricing scheme should incentivise adequate capacity to be located on the network where it is required.

Furthermore, this design implements a SR and DRO to ensure adequate capacity. The former is only intended to be used by the IISO as a measure of last resort. As those under the strategic reserve contracts are unable to access the other market modules, there should be no dampening of the wholesale prices and scarcity prices should emerge; both signals can aid in building an investment case and reducing the hurdle of raising debt finance. The DRO allow industry to directly contract for their reliability through agreements which can vary in length to also promote raising of debt for new investment opportunities whilst securing capacity to meet demand.

Objective three: Optimal investment: Is the lowest possible cost resource built to meet demand?

Similarly to objective two, the proposal calls for the removal of the capacity market which is replaced by a SR in combination with DRO. This reflects a move to allow market participants to secure the reliability they wish with a final backstop via the SR to be called upon under emergencies - rather than procuring this service through an outdated mechanism which has to date amortised fossil fuel generation plants. This is designed to promote optimal investment into the technologies and services deemed necessary by those operating within the electricity system. Furthermore, the implementation of a priority dispatch and flexibility market combination should provide clear signals on each DSP market and the wholesale market for investors on whether more generation or demand shifting capabilities are required in a particular region and whether such investment would be profitable.

Objective four: Net zero compliance: Do the rules of this institution aid in the facilitation of net zero in the context of decarbonising the electricity sector within GB?

The market arrangements detailed in chapter six have been introduced with the achievement of a net zero electricity system in mind and as such there are several arrangements which suit the characteristics of VRE. These include the bespoke markets for VRE and flexibility, the adoption of a smart energy system approach and the introduction of geographical markets (power, balancing and ancillary) at the GSP. These cater for the increased number of decentralised zero carbon technologies and service providers whilst identifying which regions will require increased VRE or flexibility for future investments. In addition, to accelerate the integration of low carbon technologies for a net zero electricity system the rules of the markets have been augmented to suit the characteristics of zero-carbon generators and flexible services, including: shorter settlement periods, closer to real time trading, pay-as-clear over pay-as-bid and the use of auctions over continuous trading. More details on proposed changes to meet this objective are found throughout appendix six.

Whilst it cannot be stated with complete certainty that these four objectives will be met without undertaking bespoke modelling, the evidence provided thus far in this chapter and throughout appendix six indicates that these objectives should be met.

6.2.2 The ‘purpose’: assessing the proposed electricity market design against the goals which underpin how these objectives are met

This section will detail how the goals set within the methodology have been supported through the proposed electricity market design.

Table 24 summarises the how the aforementioned goals of the proposed electricity market design have been achieved via the proposed augmentations GB’s current electricity market design.

Table 24 Goals of the proposed electricity market design and how these have been achieved.

Goal	How this has been achieved
Goal one: As renewables are foreseen to become the dominant player within the markets in light of net zero, the market design should	• Priority dispatch for VRE • Closer to real time trading • Shorter trading intervals • Pay as clear auctions

be designed around their characteristics.	
Goal one-b: Promote services required in an increased variable grid i.e. flexibility.	• Two-tier market approach – the flexibility market tier • SES approach employed • Local balancing mechanisms • Local ancillary markets • Emergence of scarcity pricing
Goal two: Promote market conditions which provide investment signals and dispatch for flexible technologies and services.	• Implementing DROs • Transparency of market data • Two-tier market approach • Emergence of scarcity pricing
Goal three: Promote the revealing of regional geographies.	• Altered nodal design (Location of markets at the GSP Point) • Local balancing mechanisms • Local ancillary markets • Transparent auctions
Goal 4: Open markets up to all technologies and services, regardless of their size or location on the network.	• Smaller clips sizes • Multiple marketplaces located across the GB network • Auctions over continuous trading • Increased participation from the SES approach • Local balancing mechanisms • Local ancillary markets • Altered nodal design (Location of markets at the GSP Point)
Goal 5: Promote a liquid, competitive set of markets.	• Reduced entry requirements • Marketplaces located across the networks with ease of entrance facilitated by institutional and harmonised entry requirements

	- Increased participation from the SES approach - Altered nodal design (Location of markets at the GSP Point)

6.2.3 The ‘fit for’: assessing the proposed electricity market design against the issues within this institution

Thus far a case has been made that the proposed electricity market design fulfils both the objectives and the goals required of the institution. This subsection will detail how the proposed electricity market design addresses the issues in the current market design identified in chapter five.

The issues identified in chapter five are listed in Table 25, with a succinct summary of how each of these has been addressed by the proposed electricity market design. This evidences how the proposed electricity market design will address these issues and can therefore be considered ‘fit for purpose’.

Table 25 How the proposed design can aid in mitigating the issues identified within chapter five. Negative prices have been omitted from this table as these are argued not to be an issue, but rather a signal of the demand and supply imbalance and these prices should allow for price arbitrage from flexible service providers.

Issue	Change to module(s)	Explanation for how this will aid in mitigating the issues identified within chapter five
Missing money	Coordinated markets	The introduction of new routes to market(s) can provide additional revenue streams for technologies and service providers which may otherwise find themselves out of merit.
	Nodal based pricing policy (regional investment signals)	The clearing price at each GSP node shall indicate to investors the potential value streams from the deployment of a technology, or the provision of a service, in one GSP opposed to another. Reviewing trends over time within the various marketplaces may provide investors with insights as to when particular DSP pay-as-clear Pool markets may be at risk of oversupply, which could result in the deployment of a specific technology or service provider a less attractive investment decision as prices decrease due to an oversupply in that GSP. With this information, they can avoid the deployment of a technology or the provision of a service in this marketplace, in favour of another GSP/DSP region.
	Nodal based pricing policy (constrained markets)	The nodal structure represents multiple constrained markets as opposed to the current single bidding zone in GB. As such, each GSP's clearing price will be derived at depending on the generators/resource providers within that region as opposed to the entirety of the GB network as is currently the case. In constraining the markets the price suppression currently realised within the single bidding zone will be less pronounced due to only competing against resources located in the same GSP.
	Scarcity events (transparency and	The formation of power prices at the local level will reflect regional scarcity and thus the market clearing price will allow for transparent scarcity events to emerge (Nieße et al. 2012;

	the exclusion of the capacity market)	Mengelkamp et al. 2017), a solution suggested to overcome the missing money phenomenon by Hogan (2005b). Furthermore, the capacity market has been excluded to reduce the dampening effects of this out-of-market mechanism on the emergence of scarcity prices (Energy Systems Catapult 2019).
	Implementation of DROs	The DRO is intended to offer a means for market participants to procure and provide reliability from/to other participants. The set-up of the DRO is flexible in regard to the timeframe of the contract, which could be long-term helping to unlock access to cheaper debt through proof of a contractual arrangement.
Price cannibalisation	Nodal based pricing policy (regional investment signals)	Similar to missing money. Transparent clearing prices of the bids being accepted/rejected will provide investors with the data to identify whether a GSP region is close to cannibalising prices at times of high VRE output. Furthermore, if pricing data reveals significant fluctuations in clearing pricing overtime this could be interpreted as an arbitrage opportunity for flexibility providers.
	Flexibility	The flexibility markets of both modules one and four will provide an established route for the procurement of flexible technologies. These providers of this service, when coupled with VRE, can prevent cannibalisation events through storing excess generation during peaks (Kraan et al. 2019; IRENA 2020).
Lacking flexibility	Specific markets for flexibility	The flexibility markets of both modules one and four will provide a clear reference price for flexible actions within each market module.

	A SES approach	Allowing flexible load from across the energy system silos (electricity, heat and transport) to provide flexibility will unlock large capacities whilst offering cheaper alternatives to sourcing flexibility from the electricity silo (Lund et al. 2016; Lowes et al. 2020; Sorknæs et al. 2020).
Lacking transparency	Freely available bid data	Transparent trade data for bilateral trades alongside the Pool market structures shall aid in revealing the value of specific services. Another merit of this approach is making it harder for market participants wishing to manipulate the market as has been highlighted in chapter five, section 5.1.8. Despite Ofgem's REMIT programme, there are still cases of market manipulation, aided by the lack of transparent trading practices. The transparent approach for pricing will allow data to be freely available to all interested parties which shall reduce the scope for manipulative practices, as it permits the ease of monitoring.
Not reflecting regional differences	Nodal based pricing policy (transparency of prices)	Trade data is made transparent to support revealing the value of specific services. This should identify the value for specific services at different nodes on the network. This shall also increase the transparency of prices for services and how these differ across the network.
	Nodal based pricing policy (geographically constrained)	By excluding transmission-connected technologies from directly competing in the DSP local balancing and coordinating market (modules 1–3), only technologies and resource providers within that geographical area will be represented in the clearing and bid/offer prices of these markets, bringing forward clear regional differences.
Lacking liquidity		A cited disadvantage of moving towards splitting up a single geographical market into smaller geographically defined markets is a potential loss in liquidity (Policy Exchange 2020a). Whilst some loss of liquidity will be unavoidable when reducing the geographical size of the market, it

		can be offset through increasing the number of participants operating within these regions. This is where incorporating the SES approach can help in increasing liquidity as the continued electrification of heating and deployment of EVs grow the supply of technologies able to offer flexibility, increasing the level of liquidity within a given region (Sorknæs et al. 2020). For example, National Grid ESO's 2020 FES (2020a) forecasts 37.5GW of flexibility capacity from EVs alone by 2050 indicating the scale and the quantity of participants who can compete within these geographically constrained markets, increasing liquidity.
The distribution gap		Central to the proposed electricity market design is the inclusion of electricity markets (for power, ancillary services and balancing) located at the GSP. This provides a clear route to market for distributed generators and service providers who can also trade into the wholesale and IISO markets as well. This is a shift away from the current centralised practices to one which levels the playing field by reducing the skewed energy economics that favour thermal generators.
Rising constraint and curtailment costs	Locational elements with balancing	System costs from curtailment and constraints not only remove VRE from the system, but pay mostly gas fired plants as a replacement south of the constraint border (See chapter five, section 5.1.3). Locational signals for the placement of capacity should see the deployment of generators and service providers to areas of the network where the need is highest, such as flexibility providers deploying to areas of constraints on the basis of arbitrage opportunities. Flexibility providers may deploy capacity in areas which are constrained based on observable price volatility, able to capitalise on the high-power prices at times when VRE is unable to meet demand.

	Increased presence of geographic coverage	As argued by Joos and Staffell (2018) and Policy Exchange (2020), a large cost from constraints is the re-dispatch of gas fired plants due to their location south of the constraint. With balancing mechanisms located across each GSP, it is no longer these gas fired plants which will be south of the constraint, but re-dispatch measures can be fulfilled by other, zero carbon flexible technologies and service providers instead.

Section 6.2 has outlined, discussed and justified how the proposed electricity market design can be considered fit for purpose. This is based upon objectives, goals and the means for addressing issues raised in chapter five have been satisfied.

6.3 Chapter conclusion

In response to the aforementioned issues with GB's current electricity market design and the benefits which can be unlocked through the exploitation of new opportunities, a new electricity market design is proposed. The design, built upon a review of 49 papers with proposals for electricity market reform and appraised and validated by 41 industry experts consists of several augmentations GB's current electricity market design.

A local balancing and coordinating market is introduced at each GSP coordinated by the DSP. This is achieved through a pay-as-clear Pool, balancing mechanism and ancillary market at each of the GSP nodes operated by the relevant DSP. The local balancing and coordinating markets provide a route to market for distributed technologies and services providers, and in doing so promotes a more efficient use of the network. The transparent nature of these marketplaces can help to reveal the value attributed to specific services, evidencing the investment case for generation and resource providers within a given location on the network. The existing wholesale market is standardised to reflect the GSP market structure to ease market entrance between the local and national level providing further routes to market for distributed market participants. Appropriate means to co-ordinate actions taken by both the DSPs and the IISO are proposed.

In addition to these proposed augmentations to the electricity market design, the system governance is also reviewed. First, modifications to existing governing institutions are introduced, drawing upon insights from IGov, to facilitate the smooth operation and efficient coordination of this market design. Second, in pursuing an SES approach, the design fits into the wider institutional governance by unifying the heat, transport and electricity sectors, and therefore plays a pivotal role in the overall energy sector transformation. An outcome often overlooked when proposing an electricity market design.

This chapter concludes with an assessment of how the proposed electricity market design can be considered fit for purpose against the set objectives, goals and issues.

This thesis was submitted in early 2022. At that time, the energy crisis that the UK found itself in was, in hindsight, only going to become more profound since submission. It is with this lens, that the importance of this thesis is more pertinent. For example, the high cost of generation, as explained within Chapter one, section 1.2 is driven by the cost of gas as the marginal price setter. The proposed design offers a solution to this, by having a price which, dependent on the generation and demand requirements of a region, can be met by low operating cost VRE. Indeed, this option is one that is being explored within BEIS's Review of Electricity Market Arrangements[1]. The following chapter will employ the theoretical framework developed in chapter three, alongside insights from the wider literature and analysis from the data collection to explore the third research question – What recommendations to policymakers can be identified to aid the process of contemporary electricity market re-design?

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[1] For more details, read chapter five within BEIS's REMA consultation.

7.0 Lessons on implementing contemporary electricity market re-design

Chapter six proposed a new electricity market design which will aid in facilitating GB's power sectors' net zero policy objectives. Yet, if GB is to implement contemporary electricity market re-design, there must be considerations on how to do so, including the barriers which may emerge and how to overcome them. The value of these solutions is in enabling policymakers, regulators and those interested in the process of market re-design to recognise and tackle these barriers. Left unaddressed, these barriers will result in the continued trajectory of small-scale changes to this institution; a course which is not commensurate to the urgency and the scale of electricity market re-design required to introduce the correct pricing incentives for a net zero, decentralised and energy efficient electricity system.

To facilitate this, chapter seven has been split into four sections. The first explores the current positive feedback mechanisms and path dependencies which will influence the progression of contemporary electricity market re-design within GB. Recommendations on how to overcome these are provided. These insights are informed by the analysis of interview data, the wider academic literature and the theoretical framework developed in chapter three. Building upon this, the second section brings forward a discussion on whether to continue layering, or implement a one-off displacement to introduce a contemporary electricity market re-design. The latter is argued for under the logic that whilst all complex systems will have feedback mechanisms, those in place currently within GB's electricity market design are such that it is difficult to get the required change, and therefore a displacement event is required to escape the current lock-in. Though there is still the role for layering events both pre displacement to rectify short term issues and post to facilitate the co-evolution of this institution and the wider electricity systems. A discussion on how contemporary displacement event would look in the context of the GB's electricity market design is provided. The factors influencing a contemporary displacement electricity market re-design event will differ to previous times when this form of institutional change has been utilised i.e. NETA. Due to reasons such as the increased diversity of market participants, a more active demand side and new innovative means to operate GB's electricity market design. Therefore there is value in exploring the barriers and opportunities from a policymaker's perspective to bring forward bespoke, contemporary solutions. The third section will discuss the need for political leadership to implement the proposed electricity market design via a displacement event and the issues in gathering this. The fourth will conclude.

7.1 Positive feedback loops and path dependencies

This section explores the influence of the various forms of positive feedback loops and path dependencies identified within chapter three in relation to implementing electricity market re-design within GB. It is these positive feedback loops which can result in inertia, and the lock-in of an institution along a certain trajectory. Whilst it is acknowledged that positive feedback loops and path dependencies will always exist, there is the need for these to align with an electricity market design which will facilitate a decarbonised electricity sector, not resist it. Drawing upon insights from the analysis of interview data, the wider literature and the theoretical framework developed in chapter three, strategies for policymakers will be identified to aid in overcoming these barriers.

7.1.1 High entry costs to challenge the status quo

As discussed in chapter three, section 3.1, high capital and resourcing costs incurred in challenging the current status quo are argued to typically disadvantage smaller organisations in bringing forward institutional change (Lockwood et al. 2017a; BEIS and Ofgem 2019). This section will build upon discussions with experts to provide further nuances to this discourse and identify means to alleviate this barrier.

Smaller market participants often have a single employee to facilitate multiple roles within an organisation which restricts the resources allocated to specific job, such as engaging in the process of electricity market re-design (Interview 20, 28). A representative from Good Energy (Interview 20) recalled a scenario in which changes to an aspect of GB's electricity market design were being consulted on, yet smaller market participants who would have been impacted by such changes were either unaware of the ongoing consultation or unable to allocate resources to engage with the debate. DI asserts that the development of an institution occurs via understanding how ideas become entrenched over time and the conditions in which these are 'contested, challenged and replaced'. As such, if an idea is neither contested, nor challenged, then the currently entrenched ideas on how GB's electricity market design should operate will not be replaced. Excluding the programmic and policy ideas of the typically smaller market participants, as was the case in the example provided by Interview 20, will limit the pool of alternative ideas on how to operate GB's electricity market design and omit potential innovations. Furthermore, the ingrained ideas based upon a centralised, incumbent business model ideology will not be contested, and the status quo will remain. The importance of calling upon a large and diverse portfolio of views to provide robust solutions can be evidenced by BSC modification P379[1]. Over the course of this modification, 113 representatives[2] engaged with this modification, stemming from across the energy sector, i.e. not only those involved with the BSC, but from other code bodies. An Elexon representative involved with this modification believed that the diversity of ideas was beneficial in the identification of a robust solution (Interview 28). This compounds the argument made within the proposed design in chapter six for a more integrated energy sector, compared to the siloed design currently in place. This also underpins the need to allow for the increasingly diverse number of market participants to voice their policy and programmic ideas during institutional change.

To address the issue of smaller market participants being unaware of potential changes to GB's electricity market design, there is a role for the code managers themselves to be proactive and to utilise the networks of trade associations. For example, Elexon employ operation support managers, a dedicated team contacting relevant constituents when a modification is first proposed if they believe that the views from a particular stakeholder group would be of benefit for the code modification process:

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[1] Multiple Suppliers through Meter Splitting (Elexon 2021c).

[2] To put this figure into context a discussion with Interview 28 the average attendance at a workshop within the BSC would have between six to ten representative present.

> "I don't think I can reiterate enough how important it is for our [operational support managers] management team that they are getting the right people involved in mods… having the right people in the room makes the solutions that we can present at the end of the day the best they can be".

Interview 28

Gathering views and ideas from industry can also be supported through the use of trade associations, such as the Association for Decentralised Energy. These trade bodies can disseminate relevant information to their stakeholders of any upcoming consultations on changes to GB's electricity market design which will impact them. These two methods could be employed by BEIS, Ofgem, National Grid ESO and other relevant bodies during the process of electricity market re-design to see the policy and programmic ideas of these smaller market participants contributing to the proposed solution.

Representatives of National Grid ESO (Interview 34), Good Energy (Interview 20) and Elexon (Interview 28) reported that larger market participants who they would expect to attend code modification events are also reducing their attendance, attributing this to limited organisational bandwidth[1]. Their argument was made in the context of the increased resource requirements brought on by wider energy system changes and whether these organisation can justify their involvement with this resource intensive form of governance. An example provided by Interviewee 28 was the price cap placed on retail suppliers in 2018 which has regulated the revenues which can be recovered from their customer base. This Elexon representative argued that the financial pressures from the wider energy sector have led to trade-offs being made, and the attendance to code governance meetings may have suffered as a result. Therefore, it is not only smaller market participants who are limited in their involvement in the code modification process. Fewer stakeholders raising and engaging with changes will increase the likelihood that GB's electricity market design will not co-evolve with the changing electricity sector - leading to a continued divergence. This in turn will compound, and even increase, the prevalence of the issues identified in chapter five. In reducing the pool of potential stakeholders, DI asserts that that with only those with the

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[1] Within this context bandwidth refers to an organisations finite time, finance and available expertise to commit. Limited bandwidth will result in trade-offs to be made.

financial resources to continue to raise and engage in code modifications they will be in a position to dominate the process and pursue changes which align with their own vested interests. This will be unacceptable in the context of an increasingly decentralised electricity sector with the emergence of many smaller market participants whose views will not be heard, and as a result innovations will be stifled, and the incumbent status quo will be maintained.

On a broader scale, this raises a concern of whether financial and organisational pressures will impede the engagement of market participants when more fundamental changes to GB's electricity market design are proposed, such as those discussed in chapter six. Previous examples of significant electricity market re-design, such as NETA and the EMR, were resource-intensive processes involving numerous reviews, consultations, stakeholder events, establishing expert groups, industry workshops and formal and informal meetings. With limited engagement from both smaller and larger market participants there is the concern over their attendance at such events where policy and programmic ideas are discussed, and solutions based upon these are identified; again, limiting the pool of possible solutions. However, at times when a modification is raised which does have significant impacts to existing business models, as was the case with P379 and the high level of attendance highlights that organisations will find the resources to attend these meetings and engage. Therefore, there is evidence to suggest that the high cost of challenging the status quo is no longer a burden felt exclusively by smaller market participants, but is increasingly impacting organisations across the GB electricity sector and has the potential to impede the co-evolution of this institution and the wider electricity sector.

A proposed means to reduce the resources required to engage with the various mediums of market re-design was brought forward by Interviewee 7 and 28, both representatives involved with the BSC, was the use of digital platforms to reduce time commitments and financial costs in attending meetings. This suggestion could be applied to events involved within the process of electricity market re-design by BEIS and Ofgem through holding all events online and/or also operating this process via messaging forums to allow stakeholders to respond when they have the time. This proposal has to an extent already been implemented by Ofgem, BEIS and National Grid ESO who since the normalisation of working from home during the Covid-19 pandemic have held multiple online events. This includes National Grid ESO's 'The road to net zero electricity markets' project which has run multiple online meetings to gather stakeholders' views on possible alternative market design arrangements for GB (National Grid ESO 2021f). National Grid ESO have used this online platform to collect policy ideas from a range of stakeholders to inform their assessment criteria on the proposed electricity market design which they will recommend at the end of this project. This demonstrates the applicability of utilising this method to reduce resource requirements and collect policy ideas to inform their proposal on GB's future electricity market design. If meetings are required to be held in person, and the cost is a barrier to attending these meetings, then it could be up to BEIS, Ofgem, National Grid ESO or the relevant code body, to subsidise those wishing to attend.

The suggestions above will benefit the process of integrating the policy and programmic ideas of market participants. However, there are still fundamental concerns with the process of code governance within GB which must be addressed if the co-evolution is to be achieved. Further thoughts on this are discussed in section 7.2.

In summary, there are concerns over the resource intensive nature of participating in the process of electricity market re-design in GB and challenging the status quo. The high resource requirements to participate are being compounded by wider changes in the energy sector and the limited bandwidth available to market participants within GB's electricity sector thus increasing this positive feedback loop. Suggestions have been proposed to reduce the costs of altering the status quo, which have been aided by the normalisation of attending meetings online; an implication of Covid-19.

7.1.2 Alignment to current institutional rules due to sunk costs and reducing scope for future entrenchment

The energy system governance literature suggests that resistance to institutional change will occur due to sunk investments made in existing infrastructure and current modes of operation which would be threatened if a change to status quo arises (Foxon 2002; Scrase and MacKerron 2009; Mitchell 2014b; Hoggett 2017; Sorrell 2018). An example is the associated cost of adapting operational procedures and upgrading IT systems. Drawing on experiences from NETA, the National Audit Office (2003) estimated a cost of £580million (or ~£938million in 2020 value according to the Bank of England) paid by industry to update these systems. Compounding this is how this cost will be exacerbated in contemporary electricity market re-design due to the increased number and diversity of market participants present today, as opposed the one hundred estimated by Ofgem (2000a) to have been operational at the time of NETA. Each of whom have invested into operating within the existing institutional framework and therefore will be exposed to any transitioning costs, and will likely, according to HI, resist such change. This is typical of a path dependent institution, with the sunk costs made yesterday steering away from deviations from the status quo and therefore limiting the scope for institutional change even if such changes are necessary to facilitate policy objectives.

Therefore, there is the need to consider how to minimise this barrier to implementing augmentations to GB's electricity market design. A recommendation found across the academic and industrial literature alongside the interview data is the requirement for BEIS to detail a guiding vision of the future electricity market design; whilst also providing a timeline for policies to achieve this vision and provide policy certainty required for future investment (Interview 2, 7, 11, 14, 35, 28-30) (Rotmans et al. 2001; Kern and Smith 2008; Kern 2011; Lockwood et al. 2019b; Ford and Hardy 2020). This shall aid in reducing sunk investments moving forward as investment decisions can be made at present which will align with the proposed trajectory of this institution and the subsequent trading arrangements.

This is also a suggestion by the CCC who has expressed the need for a long-term vision from government in their policies as stated in their sixth carbon budget (CCC 2020: 116).

> "The Government should develop a clear long-term strategy as soon as possible, and certainly before 2025, on market design for a fully decarbonised electricity system."

This vision must detail the key aspects of the future electricity market design, e.g. would trading arrangements be based on a continued use of uniform pricing policy, or will GB move to zonal or nodal pricing? And under the proposed timeframe that this would be implemented. The process of creating this vision, as argued by Lockwood et al. (2019b), must be transparent and legitimate, overcome the short term political pressures, and not be vulnerable to lobbying by those wishing to pursue their own interests.

Beginning with the formation of this vision, there was agreement across these datasets that this process must be primarily led by government and regulators, but encompass the views of the wider academic and industry community to gather a range of different experiences and proposed solutions to issues encountered and provide a vision which market participants agree with (Kern 2011; Lockwood et al. 2019b; Ford and Hardy 2020). As argued within Kern and Smith (2008) and Kern (2011), the inclusion of different interests in the formation of this vision is an important element of the transition as this is the starting point of a broader societal discussion on the desired direction of institutional travel. Furthermore, according to DI these discussions will allow the philosophical, programmic and policy ideas to come forward, contest current ideas and shape the construct of future institutional structures.

Through the process of creating this vision, it is argued that if the views of the above parties are included, it can mobilise actors as they are involved, create a coherent framework for avenues to be investigated to determine how realistic a specific transition course is and aid in maintaining momentum (Rotmans et al. 2001; Kern 2011).

Whilst the role of a guiding vision will aid in aligning future investment decisions to the proposed electricity market design, this will not reduce the resistance stemming from investments which have already been made. To this, the proposed design in chapter six opens up new markets and therefore can provide new opportunities for existing investments. Yet, there will be sunk investments for which the business case is no longer viable e.g. a CCGT plant seeking a capacity market contract, which is no longer feasible due to the exclusion of this module. Ford and Hardy (2020) argues that there may be the need to ‘soften the blow’ for these organisations to reduce the possible resistance they may pose to market re-design. The design of such a measure is outside the scope of this thesis, but it must be carefully designed to not provide windfall profits to fossil fuel-based investments.

BEIS’s guiding vision must be accompanied by clear milestone dates for policies which contribute to this overall electricity market design being implemented. This is required as there are concerns that the provision of a vision alone may not be enough to provide confidence for investor due to the short-term nature of political parties, nor trust in minister statements (Interview 11) (Chmutina and Goodier 2014; Hanna et al. 2016). Doing so will demonstrate a clear commitment from BEIS to implement the proposed electricity market design and aid in aligning investor expectations.

In addition to aiding in reducing future sunk costs, the transition management literature also recommends the role of a future vision as a means to bypass existing, and possibly captured, policy networks through establishing public-private networks (Kern and Smith 2008). These network would identify frontrunner policy ideas which are hoped to overcome the lock-in present in existing systems through the engagement of diverse societal actors in a reflexive and deliberative learning process (Kern and Smith 2008). The resulting vision can aid in the re-setting of the current path dependencies and break out of the current carbon lock-in through setting a strategic change in direction for GB's electricity market design. To this, the proposed design provided in chapter six would reset path dependencies through the un-skewing of current energy economics.

Another consideration is the need for Ofgem to be adaptive in their approach to facilitating BEIS's long-term vision as the design and implementation would be within their remit. This is to incorporate innovations as they emerge. Drawing upon the adaptive governance framework, Poulter (2020) argues that the capacity to adapt is required to be able to absorb changes, both foreseen and unforeseen whilst retaining the functionality of the system in question. As such, there is a trade-off between certainty and adaptability in the degree of specificity that BEIS provides for their vision of the future electricity market design. In providing a concrete vision of their intended electricity market design they may aid investor confidence to make decisions based upon future revenue pools, yet, this may lock-out future innovations which emerge during the implementation of this vision. To exemplify this, BEIS could indicate their vision of implementing nodal pricing within GB, yet, Ofgem could remain adaptive in where to locate the nodes on the network. If the decentralisation of GB's electricity sector continues to progress, a DLMP nodal structure would be more appropriate than only locating nodes on the transmission network (Liu et al. 2018; Morstyn et al. 2020; Papalexopoulos et al. 2020; Policy Exchange 2020a). As such, BEIS must provide a long-term vision and populate this with policies which show their commitment, without locking-out innovations which may emerge.

Means for BEIS to reduce the scope for further lock-in when setting out the vision, and policy steps, could be gained through the adoption of the methodology proposed by Erickson et al. (2015). In which they propose four factors to identify technologies which are likely to increase carbon lock-in. These are; equipment lifetime, the increase of CO2 emissions, the financial barriers to replace assets with low-carbon alternatives and the techno-institutional mechanisms which compound high-carbon technologies at the expense of low-carbon alternatives. As such, undertaking a methodology similar to this, BEIS can consider how their long-term vision will impact upon the deployment of a specific technology via incentivising the 'winners' of GB's electricity market re-design. If the proposed electricity market design contributes to carbon lock-in, this should be not be implemented.

7.1.3 Coordination effects and dealing with uncertainties

According to Pierson (2000), coordination effects occur when the benefit an individual receives from an activity increases as others implement the same or related actions. Resulting in the further embedding the existing path dependencies and lock-in which will influence the scale of electricity market re-design that is feasible.

There are clear merits of fostering the coordination effects, especially within the context of an electricity market design which is itself an institution based on coordinating market participants (ENA 2017; Energy Systems Catapult 2018). For example, the means of interacting with a specific marketplace such as an exchange facilitated by Nordpool benefits from more users adopting this practice as it will result in a more liquid exchange which is a requirement within an increasingly variable network (Newbery 2013; Ofgem 2019c). Therefore, the issue is not the coordination effects themselves, but how they entrench the status quo through the continued use of current practices and the resistance to move away from these, even if the efficacy of the alternative is better suited to facilitating policy objectives.

To accept that a significant electricity market re-design is required, there must also be an acceptance that the changes proposed in chapter six will bring possible short-term negative impacts upon these coordination effects. However, there are clear merits associated with implementing the design proposed within chapter six. For example, introducing the DSP will bring forward new coordination benefits, especially in the context of a decentralised electricity system in which localised marketplaces would reveal the value for operating and coordinating with other service providers in a specific area of the network.

Yet, the ultimate impact of adopting institutional rules is hard to predict (Shepsle 1986). There is the need to address the role of uncertainty as a barrier to transitioning from a known set of institutional rules to an augmented set. This is especially true within GB's electricity market design as the current rules have broadly been in place for two decades, and thus entrenched within a market participants business plans, norms and experience.

To this, Hall (2010) argues that HI can provide insights to enrich this analysis and aid in overcoming this barrier. The belief in the efficacy of a new institutional setting draws upon the insights of one's relevant expertise and prior experience, the latter being seen as fundamental to the level of confidence that an actor will place in a proposed outcome of institutional change (Haas 1992; Hall 2010). This brings forward three recommendations to aid in overcoming the barrier of uncertainty.

The first suggestion aligns with the tenets of DI, which argues that institutional change does include the views and ideas of interested parties. In other words, having input from those with the experience of operating within GB's electricity market design must be considered. This is to reassure those who will be impacted by said changes that experts, and those with experience have fed into the process of market re-design. Rather than being designed by policy ministers with limited on the ground experience alongside their own views on how best to facilitate their own policy objectives. Ofgem can utilise various mediums to collect the policy ideas from those with the various experiences, including consultations, focus groups and workshops which should shape the possible options and solutions.

The second suggestion refers to the provision of reassurances to market participants. One example of this could be for Ofgem to ensure that the existing products being traded on NEMO's are initially incorporated into the DSP and IISO's pay-as-clear market, alongside the new products better suited to the increasingly decentralised technologies and services provides as a means to aid with continuity. This would provide the ability for existing market participants to draw upon existing experiences and expertise, though in an augmented electricity market design.

The third suggestion is provided to aid in the building of reassurances through Ofgem communicating the future trading arrangements prior to their implementation. This reflect the process of how NETA was introduced, which included a seven-week parallel running of the balancing mechanism alongside 24-hour trails as a means to provide operational experience for market participants before going live (Ofgem 2000a). Furthermore, operating a parallel market will also boast politician confidence over concerns such as the 'lights going out', as any operations/technical issues should be identified and rectified prior to the go-live date.

7.1.4 Latecomers to an institution will perceive that a particular approach is widely accepted and are therefore more likely to adopt this approach themselves

The notion that latecomers would adhere to a 'widely accepted' approach is contestable. Market participants have the ability to raise code modifications which permits the framing of new problems and the proposal of possible ideas to rectify these perceived issues. This highlights that there is not an inherent acceptance of the status quo, rather an acceptance of the current rules is required to engage with this institution. More recent entrants into the GB electricity market design, such as Flexitricity, have put forward code modifications such as P415[1], evidencing that this acceptance of latecomers is not entirely characteristic and new market participants are bringing new ideas to the table.

There is an increased diversity of market participants operating within GB's electricity market who therefore have a stake in the design. According to DI, this diversity is beneficial as it brings forward more policy ideas, built upon their different and new experiences of operating within GB's electricity market design and can in turn encourage the adoption of innovative means of system operation. Building upon the example of P415, representatives of the BSC code panel and Elexon (Interview 7, 28)

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[1] Facilitating access to wholesale markets for flexibility dispatched by Virtual Lead Parties (Elexon 2019).

referred to a range of additional recent code modifications such as P344[1], P375[2], P376[3] which they argued brought forward innovations to the market design. It is these modifications which they argue can be attributed to the diversity of market participants, and the range experiences that are reflected in their novel ideas for how the efficacy of GB's electricity market design can be improved. This in turn further compounds the importance of ideas in bringing forward institutional change.

The importance of incorporating diversity when discussing institutional change is also recognised within the system innovation literature, which similarly calls for an increased participation of a diverse range of stakeholders in order to form creative ideas and implement those which show promise (De Dreu and West 2001; Rotmans et al. 2001). Innovations within a team, which could be comparable to those present in a code modification meeting, can be built by incorporating creative thinking brought forward by new participants voicing their ideas as this allows for entrenched ideas to be contested, aiding to identify more robust policy ideas and possible solutions (Cohen and Levinthal 1990; De Dreu and West 2001).

Building upon this and calling upon the literature on 'minority dissent[4]' in relation to fostering innovations, organisations must allow for minority voices to be heard and also to participate within the decision making process (De Dreu and West 2001). It is therefore the facilitators of market re-design, likely to be a combination of BEIS, Ofgem, National Grid ESO and the respective DNOs which must ensure that the minority are able to both attend such meetings and also take part in the decision-making process.

7.1.5 Actors who have political power can use this to alter the rules of the game to enhance/maintain power

Actors with the political power to alter the rules of the game, having an unfair advantage in relation to the process of electricity market re-design was a theme identified within the literature as well as by interviewees (see, for example Mitchell 2008; Geels 2014; Lockwood et al. 2019). Yet, a new discourse was identified in relation

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[1] Project TERRE implementation into GB market arrangements (Elexon 2018a).

[2] Settlement of Secondary BM Units using metering behind the site Boundary Point (Elexon 2018b).

[3] Utilising a Baselining Methodology to set Physical Notifications (Elexon 2017c).

[4] Minority dissent reflects a scenario in which a minority of group members openly voice their disagreement with a group decision with opinions expressed by the majority of the group (Curşeu and Brink 2016).

to ‘when’ the power was best exercised in the alteration of specific product requirements during its’ development lifecycle.

Between 2019 and 2022/3 National Grid ESO is developing a suit of new frequency response products. DC, dynamic moderation and dynamic regulation. This provided a unique insight into the development of a contemporary product and the processes by which market participants attempt to alter the rules of these through exercising agency. An interview with a representative of National Grid ESO highlighted that the first of these products to be introduced, DC, had already been in internal development and therefore when this product was put out to public consultation the scope for market participants to alter the parameters was limited (Interview 34). However, the two further reserve products within this reform package are at an earlier stage of development and the representative expects to see the design of these two reserve products influenced by industry, with the lobbying to influence the end product to one which favours the lobbyer’s organisational interests:

> “When you look at something such as the reserve products, we are very much producing something that is more theoretical, earlier in its lifecycle and therefore giving people a greater degree of opportunity to help put an influence on it which is what you'll see comes out of the end of that process”
>
> Interview 34

It has been argued that whilst incumbents may resist change as a means to preserve the status quo, there are times when they will attempt to shape the development of new institutions, as was the case with the EMR (Hall 2010; Moe 2016; Lockwood et al. 2019b). This theme from the National Grid ESO representative backs this assertion, with an expectation that those with the power to influence the development of the new reserve products will use it. As such, National Grid ESO must take responsibility to ensure that during the development of current and future products that equal access to permit views to be shared is supported.

This is underpinned by the is a wealth of literature which argues that incumbents within the regime will utilise relational networks and close contacts among senior officials to either resist a proposed institutional change, or alter the outcome to better suit their business interests (Lindblom 2001; Fischer 2003; Kern 2011; Geels 2014b;

Lockwood et al. 2019b). Both Fischer (2003) and Kern (2011) have focused on the role of ideas and discourses in the study of policy processes. They argue that institutional change will be influenced by what is perceived by those who can enact the change as the 'best story'. To this, one can see that the storyline surrounding the capacity market cannily played on politicians' fears over the 'lights going out' which, it has been argued, contributed to institutional change in favour of incumbent business models (Lockwood et al. 2019b).

However, access to these close contacts is not equal to all actors (Lockwood et al. 2019b) and therefore the ideas and framings which are being heard by officials are unlikely to reflect the diversity of market participants, and their policy ideas, now present within GB's electricity market. There is a wealth of literature to back up the assertion in DI that it is vitally important to hear the voices and ideas of a diverse range of participants during institutional change (Blyth 2002; Schmidt 2006; Lorenzoni and Benson 2014). It is the responsibility of BEIS and Ofgem to ensure that when views are being collected allowing the discourses being put forward by the diverse range of market participants to be included to allow them to put forward their 'story' and the case for change.

In summary, there are several positive feedbacks contributing to the current lock-in of this institution which hinders the ability for implementing electricity market re-design. Drawing upon the theoretical framework developed in chapter three, the wider academic literature and data analysis, several suggestions on how these barriers to electricity market re-design can be addressed are proposed.

7.2 How should electricity market re-design be enacted: layering or displacement?

Whilst all complex systems will have feedback mechanisms, it is those which are currently in place within GB's electricity market design which make it difficult to implement the required change. As such, there is the need to escape the current lock-in which leads to questions on whether to continue institutional change via layering, or implementing a displacement event to implement the proposed electricity market design in chapter six. To begin, this section will summarise interviewee thoughts on how to enact electricity market re-design which provides a range of merits and shortfalls for both options. These views are summarised in Table 26. Building upon this, an argument for a displacement event is then provided. Yet, there are merits to supplementing this one-off displacement event with layering events to reduce the disruptive nature of this form of institutional change, alongside facilitating the co-evolution of GB’s electricity market design with the wider electricity sector.

Table 26 Summary of participant views on the merits and concerns over layering and displacement events to facilitate electricity market re-design. Several merits and concerns with displacement do not have an attached interview reference. Where there is no reference, this view given is in direct opposition to layering which has got a reference to it.

Layering (altering the existing rules)		Displacement (replacement of the existing rules)	
Merits	Concerns	Merits	Concerns
• Allows existing contractual agreements to expire. To introduce new rules which undermine contractual agreements will reduce future investors' confidence (Interview 4,14). • Existing arrangements may only need to be altered to address an issue as it emerges, rather than re-writing the rulebook (Interview 15, 21, 22). • Alterations of the existing rules can be implemented to address concerns as	• Making continuous alterations to the existing institution can lead to a lack of coherence in the design (Interview 1, 12, 14). • Multiple alterations occurring at different timescales has to date been argued to result in a fragile instrument for securing investment (Interview 12, 14, 11). • Constant alterations require market participants to commit resources and expertise to remain aligned with these changes (Interview 9).	• Removes the difficulties for businesses to align with constant alterations (Interview 9). • Acknowledges that the current institutional arrangements are flawed and addresses these (Interview 12). • Electricity market design has lagged behind the rest of GB's electricity sector and the replacement of existing rules with new ones can update this institution in line with wider energy system changes (Interview 12, 15).	• Concerned that the replacement of rules could hinder bringing the end consumers along with this transition (Interview 14). • Sudden change could lead to an investment hiatus if there are uncertainties in the transition (Interview 23). • Need to ensure that the new rules are aligned to reaching net zero (Interview 23). • May undermine investment if existing contractual agreements

they emerge, i.e. act as band-aids (Interview 15). • Alterations to institutional rules, as opposed to their replacement, can aid in participants becoming accustomed to slightly different modes of operation and may help bring the disengaged along on the transition (Interview 3,38). • Can phase out certain elements of an electricity market design over time on the transition to a new electricity market design (Interview 11, 21). • Can pursue a least regret approach by making small-	• Unlocking investment requires stability which may be undermined by continued incremental alterations that may impact revenue streams (Interview 12). • Alterations do not recognise that the underlying institution is no longer suitable and more significant changes are required (Interview 12).	• Replacement of rules removes the incremental muddling through approach associated with layering.	are not respected, e.g. cancelled before their legal expiry date.

scale alterations (Interview 30). - Allows for addressing areas of acute concern first, before rectifying others (Interview 21).			

Drawing upon these insights it is clear that implementing either a layering or displacement style of institutional change have both merits and shortfalls. However, given the evidence presented thus far throughout this thesis it is clear that the current electricity market design is no longer fit for purpose, and there is need for a displacement event to augment this institution. The following section explores and evidences this assertion within the context of the GB electricity market design before considering how a displacement and layering events should be used in tandem.

7.2.1 Re-alignment between Great Britain's electricity market design and the broader electricity system

GB's electricity market design as an institution is lagging behind the rest of the electricity system which underpins several of the issues discussed in chapter five. There have been two decades of innovation and change within the electricity system since the introduction of NETA. Though the electricity market design has evolved continuously during this time, it is clear that it has not kept pace with the wider system changes which can be attributed to the incremental approach brought forward by current code governance. In this time a divergence between GB's electricity market design and the electricity sector has grown, reducing the efficacy of this institution which increasingly fails to reflect the characteristics present within the electricity sector. The policy feedback theory (Smith 2020) and socio-technical perspectives literature (Fuenfschilling and Truffer 2014) both emphasise that technological advances and institutions must co-evolve, as new technological advances engenders new opportunities and/or challenges which require the re-design of existing policies (Hoppmann et al. 2014). This has occurred within the GB electricity market design, with challenges arising due to the advent of new technologies not fully addressed, reducing the means to utilise the opportunities which stem from their deployment.

Implementing a displacement style event provides the opportunity to address these inefficiencies in one go, rather than making amendments to specific modules. The latter may have knock-on impacts on other modules as the institution as a whole has not been considered during the process of re-design. The following sub-sections will evidence the need for an initial displacement style of event.

7.2.2 Time-bound need for action

According to the IEA (2021), net zero necessitates ceasing construction of fossil fuel-based plants. However, under the current electricity market design within GB, there are still financially viable routes for fossil fuelled generators, such as via the capacity market. Therefore, these routes to markets must be urgently re-designed to facilitate the entrance of net zero-compliant technologies and service providers instead. This needs to be completed as soon as possible to re-distribute how value can be accessed to reduce the investment case for fossil fuelled technologies. However, the current layering regime has to date only resulted in small scale amendments, to modules such as the capacity market which has allowed CCGT contracts to continue being procured. For example, the 2020 T-4 capacity auction saw 26,446MWs of capacity awarded to CCGT which will continue to paid up until 2024/25 at the earliest (National Grid ESO 2021g).

Furthermore, the longer the existing institutional set up remains, combined with the increasing number and diversity of market participants investing upon this setup will exacerbate the aforementioned positive feedback loops. This in turn will contribute to the current carbon lock-in, and increase the resistance to implementing the augmentation of this institution which is required. As argued throughout section 7.1 the increased diversity of experiences can contribute to increasingly robust solutions. Yet, actually enacting the change itself may be impeded as the change will subsequently impact more market participants. This view was neatly summarised by a representative of Elexon:

> "I think it's a relatively concrete downside of having more market participants, you get more idea for change and better ideas which are more robust, but it is also more difficult to do them as they affect more people."
>
> Interview 28

Therefore, not only is implementing electricity market re-design time-bound by the need to address climate change, the longer the current institution remains the more entrenched it will become, compounded by this increased inertia due to more market participants experiences the positive feedback loops explored in section 7.1.

A layering approach is unlikely to address the fundamental changes required within GB's electricity market design, nor mitigate the concerns over further inertia stemming from continued investment into the already outdated design. Whereas a displacement event would allow the market designers to implement the fundamental alterations required to make GB's electricity market design fit for purpose in a shorter timescale, reducing the risk of further entrenchment in the current institutional set up.

7.2.3 Reset the path dependencies

The definition of a displacement event is the "removal of existing rules and the introduction of new ones", and therefore has been argued to aid in the breaking down of the current path dependencies which limit institutional change (Unruh 2002; Mahoney and Thelen 2010a: 15).

For example, several interview participants referred to the uncertainties of the outcomes from existing programs within the energy system as a source of resistance for introducing further electricity market re-design (Interview 28, 30, 34, 36). Themes of uncertainty, concerns about adding complexity, not being sure of the outcomes from existing programs and arguing that there is already a high level of change in occurring within the electricity sector which is requiring the resources of market participants were all expressed as justifications for resisting additional institutional change.

Furthermore, by implementing a displacement event these new rules can break out of the existing lock-in and provide a new direction, determined by BEIS's guiding vision, reducing the impact of the current path dependent trajectory. Conversely, a single displacement event can incorporate the outcome of multiple layering events. Continually implementing additional changes to the existing rules via layering events can therefore contribute to the path dependent nature of GB's electricity market design, as elements of the institutional bandwidth is expended on ensuring that the organisation remains aligned to this evolving institution; as failing to do so could lead to financial penalties.

7.2.4 Utilising both displacement and layering events in tandem

A displacement event is a disruptive approach which will have far reaching consequences throughout the electricity system. Business models which don't align with the proposed design will see their incomes reduced, end consumers will have to re-evaluate their relationship with the electricity sector and historic investments may be left stranded. To this, a displacement event should therefore not be a common occurrence, and is only justified within the context that GB's electricity market design needs urgent and significant augmentations. As such, there is a role for layering events to be used in tandem, owing to their less disruptive nature and means to aid in the co-evolution of GB's electricity market design and the wider electricity sector.

The process of electricity market re-design via a displacement event cannot be enacted overnight, but requires a substantial amount of time and preparation to be conducted prior to the augmentation's implementation date. For NETA this preparation period was between 1997-2001 which included consultations, workshops and public seminars to gather informed views on how to address the key issues identified via market re-design (OFFER 1998; Ofgem 2002). During this four-year period prior to NETA's implementation there were still alterations to the existing rules of then England and Wales' electricity market design. For example, the Market Abuse Licence Clause was introduced in 1999 by Ofgem as a means to reduce the scope for generators to exercise market power throughout the remaining life of the Pool and the first few years of NETA (Ofgem 2000b). This demonstrates how layering can be used prior to the displacement event in applying a 'band-aid' to address short term issues. In the context of contemporary electricity market re-design in GB, layering events can be used to increase routes to existing marketplaces for decentralised and variable technologies and service providers. This could include the continued opening up of National Grid ESOs' balancing mechanism until the DSP's local balancing mechanism goes online. A go live date set by BEIS and Ofgem would provide further clarity on the end date of such temporary measures, ensuring that no one is surprised when these measures are phased out.

In terms of post-displacement event, i.e. once the proposed electricity market design in chapter six has been implemented, there are still benefits to utilising layering events. Both the institutional theorist Hall (2010) and the political theorist Shepsle

(1986) agree that the impacts of adopting new institutional rules are hard to predict. As such, there are likely to be unforeseen impacts which will need to be addressed post-displacement, and layering offers a means to address these in a way which is less disruptive than implementing another displacement event. The use of layering is a means of incorporating adaptive governance within GB's electricity market design, by allowing innovations/issues to be addressed through the alteration of the existing rules. However, for GB's electricity market design and the wider electricity system to co-evolve using layering techniques, code governance must be reformed to address the current issues present which impede the ability for continual changes to occur in a timely manner.

In summary, the feedback mechanisms currently entrenched in GB's electricity market design are hindering the scope for implementing the necessary augmentations required for this institution to be fit for purpose. As such, a displacement form of institutional change is recommended, based on the argument that such an event will help:

- Re-align GB's electricity market design and the wider energy system
- Implement the changes under the time-bound need for action
- Reset the path dependencies

However, a displacement approach is disruptive and there will be far reaching consequences of implementing this style of institutional change. This is only necessitated in this context given how much work is needed on GB's electricity market design and the urgency to do so. Therefore, there is a role for layering events to be used in tandem, owing to their less disruptive nature and the ability for continual changes to be implemented to aid in the co-evolution of this institution and the wider electricity sector. Yet, the success of this is reliant on appropriate code governance being introduced; failure to do so will result in a scenario akin to today and necessitate future displacement events which should be avoided if possible.

7.3 Prospects for electricity market re-design within GB

It was a widely shared view amongst interviewee representatives and the wider literature that 'political will' is needed in order to introduce more significant augmentations to GB's electricity market re-design (Interview 5-7, 10, 18, 21, 23, 25, 28, 38) (Allen et al. 2013; Chmutina and Goodier 2014; Seto et al. 2016; Ford and Hardy 2020). This term has been commonly applied as a catch-all concept, resulting in a vague meaning which does not enrich understandings into the political and policy process (DFID 2004). The now defunct Department for International Development defined political will as "the determination of an individual political actor to do and say things that will produce a desired outcome" (DFID 2004: 1). Taking this definition forward omits the vague nature of this term and allows it to be used as an analytical tool.

The need for political will refers particularly to the 'veto players' introduced in chapter three, who in the context of GB electricity market re-design are BEIS and Ofgem and to a lesser degree National Grid ESO. This section will explore their stances on implementing significant augmentations to GB's electricity market re-design by using the example of nodal pricing. This has been selected as it is a fundamental alteration to GB's current trading arrangements that holds similarities with the proposed design in chapter six.

It is clear that the muddled rights and responsibilities of these veto players is hindering action being taken on implementing electricity market re-design (Mitchell and Hardy 2021). Ultimately, it is the responsibility of BEIS to initiate the process of electricity market re-design when augmentations require legislative change and parliamentary time (which that of chapter six will).

As will be shown below, both Ofgem and National Grid ESO[1] are considering the possibility of implementing nodal pricing within GB, yet neither have the agency to bring forward their recommendations – although Ofgem, if instructed to by BEIS, would oversee the augmentation of GB's electricity market design.

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[1] That said, the proposed evolution of National Grid ESO into an ISO would also include a role for providing targeted advice on the impact of future decisions on the energy system, including the topic of energy market design (Ofgem 2021b), and as such in the future this ISO would have more agency for this organisation in the process of electricity market re-design.

National Grid ESO is currently undertaken their net zero market reform work package, in which the outcome will be the assessment, modelling and recommendation of an alternative market design structures within GB; of which one of the proposals considered is nodal pricing (National Grid ESO 2021h). Ofgem in December 2021 released a tender to deliver a technical assessment of nodal pricing within GB with the aim to understand whether this would enable a cost-effective, secure pathway for a decarbonised power sector (Ofgem 2021d). This is a new narrative which diverges from previous Ofgem literature which has dismissed nodal pricing for reasons which fall into the category of going against the current status quo i.e. how nodal pricing divergences from the self-dispatch model currently in place within GB (Ofgem 2017c, 2019d, 2021b). Ofgem in their tender acknowledges that nodal pricing has gained recent traction from a range of reports focused on GB, such as CMA (2015d), Aurora (2020) and Energy System Catapult (2021). All of which provided evidence of the merits stemming from the adoption of this pricing policy and has likely underpinned Ofgem's newfound interest. However, even if both National Grid ESO's and Ofgem's work on nodal pricing further evidences the merits of introducing a more locational based electricity market design within GB, the decision will ultimately remain with BEIS on whether such a process would be pursued.

In contrast to both National Grid ESO and Ofgem, in reviewing BEIS's policy documents reveals little discussion of nodal pricing. The only reference to nodal pricing was found within the Government's Response to their consultation on 'Enabling a High Renewable, Net Zero Electricity System: Call for Evidence', in which they acknowledged several respondents lobbied for the implementation of nodal pricing; however, BEIS did not provide a commentary on the scope for implementation (BEIS 2020g). Furthermore, a review of wider literature on the future of GB's electricity market design published by BEIS provides considerable evidence of a preferred layering approach to institutional change (BEIS 2019d, 2020h, 2020a, 2020i, 2020f). This can be summarised in a quote:

> "whilst we need to begin to consider the longer-term market design for the delivery of net zero, we are not imminently embarking on a major restructure of our market framework" (BEIS 2020a: 17).

This approach of incrementally adjusting existing mechanisms was reinforced in the 2020 Energy White Paper which in relation to the electricity market design heralded the role of the CfD in bringing forward offshore wind deployment, and how this mechanism will be used to continue to do so (HM Government 2020).

In summary, Ofgem and National Grid ESO are undertaking work which will lead to recommendations on the proposed electricity market design for GB. These two organisations are demonstrating the determination to evidence alternative means for operating GB's electricity market design, yet neither have the ability to enact these wider market reforms which must come from BEIS. However, there is no clear evidence that BEIS will initiate these reforms, and instead continue to tweak existing mechanisms. Doing so, as argued in section 7.2, is not an appropriate means of reforming this institution given the breadth of change required and the urgency to do so.

7.3.1 Understating the risk

Second, there is the concern that BEIS does not fully acknowledge the significance of the issues present within GB's electricity market design, and therefore understates the need for institutional change. The notion that GB's electricity market design operates on a 'technologically neutral' basis and 'level playing field' is a common discourse within BEIS literature. This was also reflected by representatives of this organisations which was interviewed (Interview 21). Evidence presented in Figure 31 in chapter five illustrates several market participants from across the electricity sector who expressed a concern that the current electricity market design does not operate on a technologically neutral nor level playing field; none of whom were representatives of BEIS.

The HI literature suggests that this is to be expected as the state is considered to not be a neutral player and political arrangements can empower certain groups whilst marginalising others (Fligstein and Calder 2015). However, this is a dangerous narrative given the power of ideas and discourses in defining the problem statement. With this veto player asserting that GB's electricity market design is currently operating on a level playing field and is technologically neutral downplays the need to consider augmenting the current electricity market design to address these issues. That said, there is need to recognise that no electricity market design is truly technologically neutral as the setup of the rules will inherently favour one form of resource provider over another.

The need for BEIS to recognise the issues currently present within GB's electricity market design to justify enacting electricity market re-design highlights the value of chapter five. This chapter synthesises a range of views from the literature and interviewee participants to provide a clear summary of the issues currently facing GB's electricity market design. As such, BEIS should see this compilation of issues as clear evidence that the electricity market design neither operates on a level playing field or on a technologically neutral basis and to demonstrate the clear need to address the failing efficacy of this institution.

7.3.2 BEIS must act

This section has thus far argued that the rights and responsibilities of enacting electricity market re-design within GB is muddled, yet, it is the responsibility of BEIS to see this package of work implemented. At present, government provides a regulatory steer towards a specific policy objective, and then leaves the market to select the means to meet this end (Mitchell 2008); with some regulatory intervention with the market such as the CfD and the capacity market. However, this approach of leaving the market to facilitate the UK's net zero power sector policy goals is insufficient as the electricity market design and its incentives were not designed to facilitate this policy objective (See chapter one, section 1.6 and Table 3 for the relationship between the augmentation of GB's electricity market design and policy objectives). Therefore, as the objectives of this institution have changed so to must the electricity market design which requires a proactive stance from BEIS.

The utilisation of political will by a policymakers within BEIS to propose an alteration to an institution which is central to the security of energy supplies could be considered a risky endeavour for politicians as this involves altering the institution which oversees security of supply (Interview 4). To quote a senior official from Lockwood et al. (2019: 6) "there is one thing that is going to get you fired, and that is this [the lights going out]". Yet, the need to electricity market re-design is urgent and should not be implemented or not depending on whether there is a perceived political risk, rather, focusing on the merits that this work package would result in for the British public.

As stated within chapter one, section 1.2, augmenting GB's electricity market design offers a means to reduce reliance on volatile global commodity markets, and instead augment towards an electricity market design which is based upon the utilisation of domestic resources, be that DER, energy efficiency, demand-side and VRE located across GB. Doing so will bring forward numerous benefits to the British public such as giving them agency to engage and provide services whilst being paid to do so, reducing balancing costs of the network which will be reflecting in their subsequent energy bills and reduce pollution. The government is elected by the people to represent their best interests, and this thesis has clearly stated how implementing an augmentation of the GB electricity market design is in the best interest for the British public and therefore BEIS are responsible for implementing this. Failure in BEIS to be proactive now will only lead to the compounding the issues which will need to be dealt with at a later date. Yet, to delay will result in larger consequences and more resistance as further investments are made on the basis of the already outdated institution.

It is not only GB which is considering the efficacy of their electricity market design; indeed this is a consideration for countries located on continental Europe as well. As such, if BEIS were to act first there are opportunities for BEIS to become a thought leader and benefit from being the ‘first mover’. A whitepaper by the Germen Federal Ministry of Education and Research (2021) argues for Germany to lead the process of market re-design from a uniform to nodal design. They argue that being the first country within the EU to make this move would have the additional benefits of setting the standards and develop the technologies which following countries would likely later adopt. This would result in the exportation of skill, technologies and digital literacy, to neighbouring regions whilst creating and supporting domestic job and drive growth within this industry. The implementing of a market re-design would therefore contribute for the UK’s Industrial Strategy further evidencing the need for BEIS to be proactive.

Furthermore, a compilation of various policy documents from across HM Government, BEIS and Ofgem, and their intended outcomes have been summarised in Table 27. The purpose of this table is to identify how the process of electricity market re-design can contribute to the intended outcomes of these various programs and offer a more efficient use of BEIS’s available political will.

Table 27 A summary of documents published by both BEIS and Ofgem, the scope of this research and how this can be addressed in part by electricity market re-design.

Document	**Scope**	**How this can be addressed through electricity market re-design**
Smart system and flexibility plan (BEIS and Ofgem 2021)	Discusses the exploration of local markets for flexibility.	Markets for flexibility have already been validated within the proposed design.
	Discusses the need for coordination in an increasingly decentralised electricity system.	One of the key roles of an electricity market design is to coordinate the various market participants, and the introduction of the DSP will aid in the coordination of the increasingly decentralised electricity system.
Industrial Decarbonisation Strategy (HM Government 2021)	Focuses on how to reduce emissions in line with net zero.	Addressing the current skewed economics found within GB's electricity market design which still favour traditional fossil fuel technologies can aid in the deployment of more zero-carbon technologies.
The role of vehicle-to-X energy technologies in a net zero energy system (BEIS 2021f)	Calls to understand how vehicle technologies could contribute to a net zero energy system and possible business models.	This approach shares parallels with the SES approach which has been incorporated into the proposed electricity market design. The design does not offer technical solutions, but provides ideas on how these vehicles can access markets and secure revenues for their services.
Enabling a High Renewable, Net Zero Electricity System: Call for Evidence (BEIS 2020a)	How to support and adapt to innovative technologies and business models.	Markets have been cited as a means to spur on innovations through competition (Newbery 2002; Ringel 2003; Geels 2014a; IEA 2016). The proposed design reduces the scope for government intervention within the electricity markets and therefore reduces pre-determined outcomes by this central entity and instead promotes innovations to emerge from competition marketplaces.

In summary, the ‘grey area’ for rights and responsibilities for implementing the process of electricity market re-design and lack of will from BEIS will undermine the ability to implement electricity market re-design. As without BEIS’s support, which is not forthcoming, it is theorised that layering events will continue to dominate how this institution evolves. Exploring why such will is not forthcoming identified three themes, the associated political risk, understating the importance of electricity market re-design and the muddled rights and responsibilities of the veto players. Yet, there are clear merits to implementing electricity market re-design within GB and it is also in the best interest of the British public to do so. Therefore BEIS must be proactive and instigate augmentations to this institution.

7.4 Chapter conclusions

In conclusion, this chapter has integrated findings from the data collection, the theoretical framework developed in chapter three and the wider literature to address the third research question. Adopting this approach provided a means to critique the process of contemporary electricity market re-design and bring forward several recommendations for policymakers on overcoming the identified barriers to this institution’s evolution. In doing so it has evidenced the use of the theoretical framework for future academic research into this topic. This concluding section will summarise the key arguments.

A range of barriers to contemporary electricity market re-design within GB have been identified using the five forms of positive feedback loops and the phenomenon of path dependency. There was a plethora of mechanisms behind these barriers, spanning economic; e.g. sunk costs, cultural; e.g. changing current trading practices, and political factors; e.g. the veto players and the agency to actual enact electricity market re-design. The range of barriers and the mechanisms behind them call for bespoke solutions, such as the formation of a guiding vision by BEIS of the future electricity market design for GB.

Underpinning many of these barriers are factors which were not as prevalent during NETA, such as the greater number and diversity of market participants. This structural change has a number of implications for the process of contemporary electricity market re-design which must be acknowledged by policymakers in order to successfully deliver change. The greater diversity of market participants who are bringing forward new and innovative means to operate within GB's electricity market design provide new experiences of how GB's electricity market design could be structured and by incorporating these views into the process of electricity market design, innovations can be brought forward. A key recommendation is therefore the need for policymakers to incorporate these voices, programmic and policy ideas and there are a range of means to facilitate this, such as building upon the normalisation of facilitating meetings online. However, this increased diversity may also contribute to a growing resistance to future electricity market re-design, as the additional participants may add to the inertia stemming from the positive feedback loops and further entrench the current path dependencies, justifying the need for BEIS to act with urgency.

Building upon this, the two applicable means of institutional change according to Mahoney and Thelen (2010b) were discussed, and their merits and shortfalls summarised. There is clear evidence to support a displacement style of institutional change, as opposed to a continued layering trajectory. In the context of GB, these reasons include the time-bound need for market re-design to aid in facilitating net zero objectives, rectify current issues in a holistic manner, reset the current path dependencies and escape the current carbon lock-in. Layering should instead be complementary and used both before and after the displacement event. This is to address short-term issues which emerge during the research phase prior to the displacement event going live, and also afterwards to adapt to any unintended or unforeseen consequences and allow for the co-evolution of this institution with the wider electricity sector. Though, effective co-evolution is dependent upon the future of code governance which Ofgem, at the time of submission, has not announced.

Finally, BEIS holds the agency to enact the process of electricity market re-design. Yet, it is clear that such intentions are not forthcoming. Whilst the work being conducted by both National Grid ESO and Ofgem is useful in that they will provide case studies, modelling and evidence for alternative modes of operation, without BEIS implementing these measures this institutional change will not occur. This is a sign of poor governance and prioritisation, as BEIS should recognise that electricity market re-design offers a way to address several policy goals (See Table 27) whilst reducing reliance on international commodity markets by instead utilising domestic VRE technologies, the increasingly active demand side and energy efficiency measures. Therefore, it is in the public's interest for BEIS to enact electricity market re-design.

The following chapter shall conclude this thesis.

8.0 Concluding remarks and future avenues for research

8.1 Introduction

The previous chapter addressed the third research question, providing a discussion on the barriers and possible solutions to implementing contemporary electricity market re-design within GB. This final chapter provides a reflection on the results, focussing on each research question in turn to consider the contribution of this research to the field. This section is presented as follows: 8.2 will summarise how each of the research questions have been addressed; 8.3 will detail the limitations encountered within this study and avenues for future research; 8.4 will discuss the key contributions and findings, splitting this into both policy implication and academic contributions; 8.5 will provide a final reflection.

8.2 Answering the research questions

The aim of this thesis is to provide the blueprints and lessons for the implementation of a fit for purpose electricity market design for GB, addressing two gaps within the academic and broader policy literature. To facilitate this aim, three research questions were examined. As a reminder, these were:

- RQ1: In what ways is the electricity market design in Great Britain no longer fit for purpose?
- RQ2: What does a fit for purpose electricity market design for Great Britain look like?
- RQ3: What recommendations to policymakers can be identified to aid the process of contemporary electricity market re-design?

This chapter will begin with an exploration of how each of the research questions have been addressed.

8.2.1 RQ1: In what ways is the electricity market design in Great Britain no longer fit for purpose?

This research question was primarily examined within chapters two, three and five, which compiled the issues of the current electricity market design in GB. A range of sources were synthesised to identify these issues, drawing upon governmental, academic and industrial literatures, workshops, conferences, the analysis of 41 interviewee responses and involvement with external projects.

The four objectives of GB's electricity market design discussed in chapter two were used to assess whether the electricity market design was fit for purpose. These objectives are:

- Efficient dispatch: Is the lowest cost resource being activated to meet demand?
- Adequate capacity: Is there enough capacity to meet demand?
- Optimal investment: Is the lowest possible cost resource built to meet demand?
- Net zero compliance: Do the rules of this institution aid in the facilitation of net zero in the context of decarbonising the electricity sector within GB?

Chapter two reviewed the efficacy of the current electricity market design and identified that of these objectives, only the first is evidenced as being facilitated by the wholesale market. Further to this narrative around the inefficiencies within GB's electricity market design, chapter five detailed further issues within this institution.

Central to these issues is the view of GB's current electricity market design as outdated in the context of the current electricity system. This is based on the fact that the electricity system itself has undergone rapid change, whilst the electricity market design within GB has been updated through incremental changes, resulting in a divergence between the formal institution and the realities of the electricity system. The need for changes to be applied quickly and holistically (which has not been the case to date) is a key principle which will be referred to in RQ3.

8.2.2 RQ2: What does a fit for purpose electricity market design for Great Britain look like?

The proposed electricity market design for GB was the result of an iterative methodology explained in chapter four. The process involved applying insights gained from a review of 49 papers with proposals for electricity market reform to create a strawperson design. This design was then appraised and validated through 41 semi-structured interviews, presentations at conferences and via peer review (See, Pownall et al. 2021) (A full copy of this publication can be found in appendix seven).

This thesis advocates the introduction of a balancing and coordinating market at each of the GSPs. This is realised through a pay-as-clear Pool market, a balancing mechanism and an ancillary market at each of the GSPs which are governed by an enhanced version of the current DNO, known as the DSP. These 'local' markets bring forward regional differences which indicate to investors the optimal positioning on the network of a specific technology and/or service provider to financially incentivise their optimal location on the network; doing so will aid in clarifying the energy economics of the distribution network as opposed to the largely centralised regime at present. The wholesale market is also reconfigured to reflect the two-tier marketplaces introduced at each of the GSP points i.e., a dedicated marketplace for VRE generators and a flexibility marketplace. This is to reflect these balancing and coordinating markets to aid with the coordination between marketplaces across the network.

The proposal consists of several augmentations from the current electricity market design within GB:

1. Markets located on the distribution network
2. Local coordinating and balancing markets located at the GSP
    - Pay as clear Pool market
    - Two-tier market: Priority dispatch for renewables, and a flexibility market as a residual top up
3. Evolution of the DNO to a DSP to facilitate the coordination of the GSP Pool market, balancing market and an ancillary market at each GSP

4. Wholesale and IISO markets set up to reflect the structure of market set up at the GSP
5. Two gate closures
    - DSP's gate closure first, followed by final gate closure for entire network, overseen by the IISO
6. Replacement of the capacity market with a strategic reserve and decentralised reliability options

Chapter six with appendix six provide a detailed explanation of these alterations and the nuances of how such market modules would function, e.g., the coordination between these modules and the timescales of the procurement process and details such as the suggested clip sizes. The outcome of this is an electricity market design which is suited to the characteristics of a net zero electricity system which does not provide financial incentives for fossil fuel technologies, empowers the end consumer, incentivises appropriate locational deployment for VRE and flexibility providers whilst bringing forward an energy efficient use of the network. The blueprints provided in answering this research question fulfil the CCC's (2020) recommendation for a long-term strategy on a market design for a fully decarbonised electricity system.

Key to this proposal is the need for a whole system approach, which has been achieved by integrating this proposed electricity market design into the wider governance framework provided by IGov. The proposed electricity market design brings forward the role of several organisations which are of vital importance to the functioning of this electricity market design. For example, the DSP will create competition at the local level, operate marketplaces to help identify where value can be accessed and in doing so revealing the value for technologies and service providers on the distribution network. All of which will aid in the redistribution of access to wealth in GB's electricity sector and bring forward new and innovative means to operate the electricity market.

Building upon Table 19 in chapter six, appendix four and interviewee data analysis there is a consensus of the need for electricity market re-design - yet there is no agreement on the scale of change which should be implemented or how such a design should look. This underpins the need to acknowledge that there will be trade-offs where winners and losers will emerge. Therefore, it is important to reflect upon the decisions made. The trade-offs made within the process of creating this electricity market design and the justifications behind these decisions are summarised in appendix six. The decisions taken both align and disagree with governmental, industrial and academic proposals of a future electricity market design for GB. The exclusion of the capacity market is an example of this, with cited literature both in agreement for the exclusion (Blyth et al. 2020; Energy Systems Catapult 2021) and opposing (Rosell et al. 2018; Xu 2019). This is also in direct contrast with governmental proposals which intend to tweak this mechanism instead of replacement (BEIS 2019). In noting these trade-offs, the researcher's positionality was assessed in chapter four, section 4.4, as there is an inevitable degree of subjectivity, however small. It is therefore of paramount importance to be clear about decisions taken for BEIS and Ofgem to recognise that any proposed design is unlikely to see approval from the entire industry, and will be met by resistance. This reinforces the significance of the research findings identified in RQ3.

8.2.3 RQ3: What recommendations to policymakers can be identified to aid the process of contemporary electricity market re-design?

The third research question was investigated primarily in chapter seven. Guided by a historical and discursive institutionalist lens developed and justified in chapter three, insights from the wider literature and analysis of data collected. The third research question has identified several barriers which may hinder the process of contemporary electricity market re-design within GB as well as proposing solutions to overcoming these.

These barriers were identified within chapter three as stemming from the path dependent nature of institutions and the contributing positive feedback loops. As was evidenced in chapter seven, each of these can be attributed to causing resistance within the process of electricity market re-design:

- Path dependency and shifting away from positive feedback loops
- Uncertainties within a re-design
- Investments made on the basis of the current status quo
- Electricity system is already undergoing multiple transitions
- The muddled set of rights and responsibilities across organisations involved within the process of electricity market design within GB

- The stance from BEIS that significant augmentations to the electricity market design of GB are not immediately forthcoming

These difficulties are exacerbated by the increased number and diversity of market participants now active within GB’s electricity market design. This increased diversity of market participants was shown to provide new opportunities and innovations in terms of how this institution operates. These will originate from bringing forward the experiences of these diverse participants who are now operating across new locations on the network, with new business models and alternative means of providing grid services such as utilising the demand side for flexibility. This signifies the importance of opening up marketplaces for these diverse participants to create a business case for these new innovations - but also voice their policy ideas during discussions on the future electricity market design. Failure to do so will continue the regulatory capture from incumbents and reduce the scope for innovation. On the other hand, the higher number of market participants will likely increase inertia and resist institutional change due the increased number of participants experiencing the aforementioned positive feedback loops and alignment with the current path dependencies.

A variety of solutions have been proposed to overcome these barriers to implementing electricity market re-design. The provision of a guiding vision on the future of GB’s electricity market design from BEIS, accompanies by clear milestones, will promote overcoming several of these issues.

The second consideration of RQ3 is how electricity market re-design should be implemented. As evidenced within chapter three and seven, GB’s electricity market design is currently evolving through incremental layering. This fails to address fundamental issues within GB’s electricity market design and does not recognise the time-bound requirements of meeting the 2035 zero carbon power sector target. In addition, the longer these incremental adjustments are maintained, combined with the increased diversity of market participants investing upon these current rules, the further entrenched the current positive feedback loops become. This in turn will increase resistance to future alterations to the status quo. As such, the need for a market re-design is not only time bound in terms of dealing with climate change, but is also needed as a means to reduce the levels of inertia which will only increase over time, compounding the current carbon lock-in of this institution.

For these reasons, a displacement style of institutional change is recommended to re-align GB’s electricity market design with the contemporary electricity sector and to provide holistic change, implement the fit-for purpose design in a short time period and reset path dependencies. The implementation of the proposed electricity market design would broadly reflect the process used to implement NETA. Layering events are proposed to be used both pre, and post implementation of the electricity market design as a means to address short term issues before the implementation of the new electricity market design. Moving forward, it was acknowledged that a displacement event will lead to major disruptions to the current status quo, and whilst necessary, such events should only be used under extreme circumstances to rectify significant issues. As such, layering events should be used post-displacement event in order to support small-scale changes which allow for future innovations to be incorporated.

This will introduce adaptive governance and allow for the co-evolution of this institution and the wider electricity system to occur, omitting the need for further displacement events. However, a reflection on the current governance structure for layering events, i.e. code modifications, as argued in chapter three and chapter seven is currently ill-suited to enable needed co-evolution. It is the responsibility of BEIS and Ofgem to ensure that this is an outcome of the current code governance reform program.

The current responsibility and rights regarding introducing an electricity market re-design in GB is argued to be unclear. Ofgem and National Grid ESO are both undertaking work packages on the future of the electricity market design of GB, yet neither have the agency to enact their recommendations. It is BEIS who must take responsibility and bring forward the institutional change to the benefit of the public to whom they are accountable for. Whilst perceived barriers were cited, such as political risk and the understating of the need for electricity market re-design, these are unsuitable reasons for BEIS not to undertake this body of work and instead, undertaken augmentations to the electricity market design should be seen as an opportunity to address multiple policy issues (Table 27), align this institution with net zero policy ambitions, contribute to the UK's industrial strategy and deliver value to the end consumer.

8.3 Limitations and further research

As with all research, limitations were encountered. These are presented below.

Covid-19: Whilst Covid-19 offered a glimpse into the efficacy of GB's current electricity market design under conditions akin to a high variable electricity sector, the logistics of conducting international data collection was hindered. Despite multiple attempts to contact Danish stakeholders to hold interviews during times in which international travel was unfeasible, such as via Skype, the number of respondents was lower than intended. Whilst the number of interviews was reduced, valuable additional insights were nonetheless gathered from those who did respond, but it is possible that the lower number of interviews has reduced the confidence with which international generalisations can be made. As such, future research could provide an international comparator to cement the findings of this research.

Electricity market design constantly evolving: GB's electricity market designs and the wider electricity sector is constantly evolving with new policies emerging. These will impact the current electricity market design within GB and may lead to certain assumptions within this research as being outdated. For example, National Grid ESO's (2021) future electricity market design work, Ofgem's tender on nodal pricing and the outcomes of the various consultations proposed within BEIS's 2020's Energy White Paper are still unknown. Each of these bodies of work will have implications for the findings in this thesis. Where possible, additional literature reviews at the time of a new publication, or interviews with stakeholders informed about new and forthcoming publications have been used to mitigate this and ensure that the findings of this research are based upon the most up to date information available at the time of submission.

The forward markets: GB's electricity market design operates over a range of timescales, from years in advance up to the momentary delivery of the traded electron. The timescale of focus for this proposed design is that of the SPOT - i.e. 48 hours up to and including the delivery of the contracted service. The rationale for focusing on this timeframe is shown by the importance of operating closer to real time for VRE generating assets and flexible units (Lin and Magnago 2017; EPEX SPOT 2020). The significance of these timescales will continue to grow as trading closer to the delivery period is expected to become increasingly critical (EPEX SPOT 2020). Yet, further research into how the forward markets would operate and allow for the hedging of risk under such a new electricity market design would complement this research.

Methodological limitations: As with all research, there are several limitations of the methodology employed and this subsection will provide a reflection on these. First, the data collection method is qualitative, and this comes with trade-offs when compared to taking a quantitative approach instead. For example, the findings from a qualitative approach are based upon the researcher's interpretation of interview responses, which can be considered subjective, whereas data driven results are less so (Russell Bernard 2011).

Second, the assessment of this proposed design could therefore be further evaluated and refined by bespoke computational modelling. Yet, due to a combination of time constraints and the skillsets available to the researcher, such an undertaking was unfeasible. Therefore, future modelling would be welcomed, and indeed would be required within the research phase prior to implementation of the proposed design.

Third, there is a concern over the positionality of the stakeholders invited for interview, as those in favour of some form of electricity market re-design may be more inclined to agree to be interviewed on the subject. This concern is reduced however by the extensive evidence from academic, industrial, and governmental literature which is highly suggestive of a broad consensus in favour of the need for re-design i.e., BEIS's consultation on the Review of Electricity Market Arrangements."

8.4 Key contributions and findings

As a thesis focusing on the future electricity market within GB and lessons on the evolution of this institution, this research contributes to the growing body of knowledge on electricity market re-design. This thesis establishes several distinct policy implications and academic contributions.

8.4.1 Policy implications

Blueprint for the future electricity market design for policymakers: One of the key contributions of this thesis is the development of blueprints for a fit for purpose electricity market design for GB. This design is available to be used by both domestic and international[1] policymakers who are considering how to address specific issues with their electricity market design. This design also fulfils the CCC's (2020) argument for government to bring forward a long-term strategy on a market design for a fully decarbonised electricity system, a gap which this thesis has filled through the proposal in chapter six.

Furthermore, as evidenced by chapters five, six and appendix three, there are a vast number of proposed electricity market designs intended to deal with issues within liberalised electricity markets around the globe. Whilst these offer useful insights into how these could address a perceived issue, they do not provide a holistic electricity market re-design, as Peng and Poudineh (2017) argue. This is not to say that these proposals are without value, as they nonetheless provide a targeted solution to a specific issue with an electricity market design. However, addressing a singular issue does not always consider the knock-on impacts on the other modules of an electricity market design, which is a key concern of the incremental (layering) approach to institutional change. **Concise chapter on the issues facing GB's electricity market design:** As argued in chapter seven, one of the proposed reasons for BEIS not undertaking electricity market re-design stems from understating of this issues by the veto players. A comprehensive list of all issues facing GB's electricity market design was developed by combining insights from the academic, industrial and governmental literature and expert interviews, and producing, for the first time, a valuable resource for policymakers to evidence the need for electricity market re-design. This is important in the context of one of the findings in the previous chapter that BEIS argues that GB's current electricity market design operates on the basis of 'technological neutrality' and a 'level playing field'. By producing a comprehensive list which evidences how this

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[1] Though the design has intended for GB, and therefore whilst there are transferable lessons, there will need to be amendments to suit the local setting.

assertion is unsubstantiated, it identifies this as an area for this veto player to acknowledge and address.

Identification and lessons for overcoming issues within the process of electricity market re-design: Chapter seven identified several barriers which will be present in the process of electricity market re-design within GB and proposes solutions policymakers could adopt to aid in overcoming these. The suggested solutions are intended to aid policymakers within BEIS and Ofgem to initiate electricity market re-design in the timely manner required to reduce future entrenchment in the current status quo, exacerbating the aforementioned issues identified.

Recognition of the importance of voices in an increasingly diverse electricity sector: This thesis has proposed that there is clear merit for BEIS and Ofgem to facilitate means to collect the views of the increasingly diverse set of market participants to increase the robustness of proposed solutions. Therefore, there is the need for better tools to ensure the participation of all relevant parties to attending debates and instigate their policy and programmic ideas. Failure to do so will result in missed opportunities and loss of innovation.

Contesting the current modes of institutional change in GB: Reflecting upon chapter three and chapter seven, the application of historical and discursive institutionalism has identified and evidenced the need for a displacement event to be used in tandem with layering events. This is in clear contrast to the current mode of institutional change within the GB electricity market design. However, based on the work of Thelen (2007) it is proposed that a displacement event is necessary due to the scale and urgency of change. This in turn has large-scale implications for both BEIS and Ofgem who will need to initiate the process, dedicate resources, test the new system to ensure that the objectives of this institution are met and ensure that market participants are ready for the changes.

Presentation of research to policymakers: Throughout this PhD program there have been several events where the researcher presented the findings of this thesis to policymakers; through a presentation such as the brown bag event to BEIS (Pownall 2021) or via actual interviews with expert stakeholders in which initial findings were presented. Though it is not expected that these forms of disseminating information themselves will lead to the proposed design in chapter six to be implemented, it has been an opportunity for the discussions on the future electricity market design to be held and bring to light the need for institutional change.

8.4.2 Academic contributions

The findings from this study provide direct benefits in terms of academic value by making the following contributions:

Building upon current understandings of historical and discursive institutionalism: The use of both historical and discursive institutionalism in tandem is not a novel proposal, yet the application of this combined theoretical framework within this study has further evidenced the suitability of this in the study of electricity market re-design. The combination of the two has indeed been shown to overcome individually perceived issues. Namely, historical institutionalism has been criticised for not paying sufficient attention to the ideas of individuals and their impact on institutional change (Campbell 1998; Olsen 2009; Schmidt 2010). As shown within chapter seven, the use of discursive institutionalisms in tandem brought forward productive avenues of research in the role of ideas, and proved complementary to this shortfall of historical institutionalism. Furthermore, historical institutionalism was criticised by Scott (2013) owing to its reliance on historical cases. Yet, this is a contemporary example of institutional change which contests this notion and instead argues that this framework holds value when exploring modern institutional change as well.

Critiquing the process of market re-design: As stated in chapter three, there is a gap within the theoretical literature for a framework to be applied to the process of electricity market re-design. Such a framework is required to provide the tools for academics, policymakers and market participants to critique the process of institutional change. For example, in acknowledging that during the process of market re-design, and the mediums in which these discussions are facilitated, when there is not a suitable representation of the current diversity within the broader market the solutions are unlikely to be as robust, according to discursive institutionalism. Empirical findings justify the use of historical and discursive institutionalism as an appropriate theoretical framework to fill this gap. This thesis has developed and demonstrated this novel framework suitable for the understanding of the process of this institution's evolution which, as stated in chapter five, is likely to be a topic area of increased scholarly attention if current interests in this institution continue. Furthermore, in the context of GB's net zero power sector target of 2035, such a theoretical framework will become increasingly sought after by interested academics.

A comprehensive review of multiple electricity market design proposals: To the author's knowledge, this is the first comprehensive review of 49 papers with proposals for electricity market reform. This resource can be used by academics interested in the literature on proposed designs to support their own research agenda. Furthermore, as the interest of electricity market design continues to grow both domestically and abroad, both the appendices and the wider thesis can be used by others to explore alternative arrangements in their own domestic settings.

Evidencing the merits of modularisation: The methodology within this thesis drew heavily upon the insights from the field of modularisation. The author identified three uses of this methodology in previous publications on the study of electricity market design as shown in chapter four, section 4.5.2.3. This thesis has therefore contributed to the robustness of applying this technique. That said, the use of this technique may not be suitable for all situations. For example, if an academic wished to focus on an isolated issue limited to one module, taking this holistic approach may not be as appropriate.

Contributing to the academic field of electricity market design itself: Throughout this research the author has contributed to the academic field of electricity market design through various mediums; these include the publication of the proposed electricity market and the presentation of research findings to fellow academics at conferences such as the IREMB event. This in turn has led to a dissemination of analysis of the field of electricity markets.

The proposed electricity market design fits within the current debate within GB on the future of our electricity market design. For example, the proposed design has been referenced within BEIS's Review of Electricity Market Arrangements, which is laying the foundation for future market reform options. As such, the proposed design is at the forefront of the field of electricity market design and has bridged the theoretical process of proposing a new design with the practical aspects of implement a proposed design. Furthermore, by being one of several different design policies, the proposed design fits into, and indeed contributes to the broader debate on current policies, e.g., the adoption of a nodal based electricity market design.

Furthermore, as an academic with no financial interest in the proposed electricity market design this allowed for a critical evaluation of GB's electricity market design. This may not be feasible within studies undertaken by those with financial ties to this institution, e.g., consultancies, industry representatives and civil servants; all of whom will have their organisations key goals, messages and vested interests ingrained in their outputs. This relationship was evidence in chapter five, section 5.3.1 as those with perceived vested interests recommended minor augmentations to the electricity market design whilst those without them proposed more significant augmentations. As such, this proposed design should be considered by academics as an independent body of work with the recommendations made coming from a neutral position.

8.5 Final reflections

This thesis has demonstrated that the current electricity market design within GB is outdated and hinders the scope for the development of a net zero power sector by 2035. Looking past climate change objectives, there is also the need to consider how this institution can be improved to reduce the current increased cost of living to British households, facilitate the increasingly decentralised market participants and provide the correct economic signals across the entire network. To this, the blueprints provided here and reflections on the implementation are intended to assist BEIS and Ofgem in pursuing this necessary institutional change.

Appendix one – The process of trading electricity: an illustrative example

To explain how electricity is traded on the wholesale market, the trading of electricity into **Settlement Period** of 12:00-12:30 on the 8th of December will be used, and Figure 36 will illustrate this process.

Days to years in advance of the 8th of December, electricity suppliers such as SSE will forecast their consumer's electricity needs for this **Settlement Period** and will enter into a **bilateral contract** with an electricity generator(s) to procure the forecasted amount. Trading at this timeframe is known as trading on the **Forward/futures Market *(I)***. At this point in time, generators of firm powered plants (typically fossil fuel generators) will know how much electricity they can reliably produce and therefore sell for a given **Settlement Period** to the electricity supplier. As fossil fuel generators are firmed powered, they can sell their generation in different chunks, as illustrated in Figure 36, with this generator selling 20% 2 years in advance and 30% 1 year in advance. Not selling all generation at one point allows these generators to react to higher prices within the market over time as external events can shift the price of electricity (Pierpont and Nelson 2017). These trades of electricity are known as trading on the forward market, which are bilaterally contracts and can be facilitated by a broker such as Tullet Prebon, via an exchange such as the Intercontinental Exchange or directly between the two parties (CMA 2016d).

As the **Settlement Period** on the 8th of December is months or weeks away, the supplier's forecasts of consumer electricity needs is likely to change, i.e. weather forecasts predict a colder than expected day, and therefore more electricity may be needed for heating (BEIS 2017b). To avoid **Imbalance charges** these suppliers will need to either buy, or sell, through **bilateral contracts** electricity to reflect a change in their forecasts ***(II)***. Once again, this will typically be with firm powered generators, however there may be a few renewable generators entering into **bilateral contracts** at this point in time as weather forecasts at this point in time are more accurate ***(III)***.

On the day before the date of delivery (7th of December) and the actual day of delivery (8th of December) trading can occur on the over an **Exchange** in addition to **Bilateral trades (I*V*)**. Trades which occur during this time frame on an exchange are known as the **Day Ahead** and **Intraday markets,** which are commonly coupled to form the '**SPOT Market'**. Exchanges such as EPEXSPOT and N2EX facilitate trades over an online platform, allowing suppliers to either buy or sell up to one hour before the half hour block using pre-arranged auctions. For example, auctions which cease at 11:00am with the outcome, and dispatch schedule, determined 45 minutes later (CMA 2016b). It is within these exchanges that the majority of renewable generation will be traded, as weather forecasts at this timeframe are much more accurate, and therefore renewable generators can accurately bid into these exchanges. If there are more expensive generators on the exchange setting the clearing price, these renewable generators may receive well in excess of their costs. That said, a significant proportion of renewable generation will be traded via a power purchase agreement, which is a form of bilateral agreement which often has a fixed price for the output and will not trade via the exchange route.

At 11:00 on the 8th, trading for this half hour block stops, this is known as '**Gate Closure' (*VI*)**. National Grid ESO then opens up their **Balancing Mechanism (*VII*)** which, as described in Chapter two, Section 2.2.1.2, will have received information on any deviations on contracted positions, and whether there is the need to take corrective actions (Elexon 2017a).

If there is too much, or not enough electricity forecasted to go onto the system within this half hour, then National Grid ESO will either procure electricity or pay generators not to produce. These charges incurred, the **imbalance charge**, are then passed down to the supplier or generator responsible.

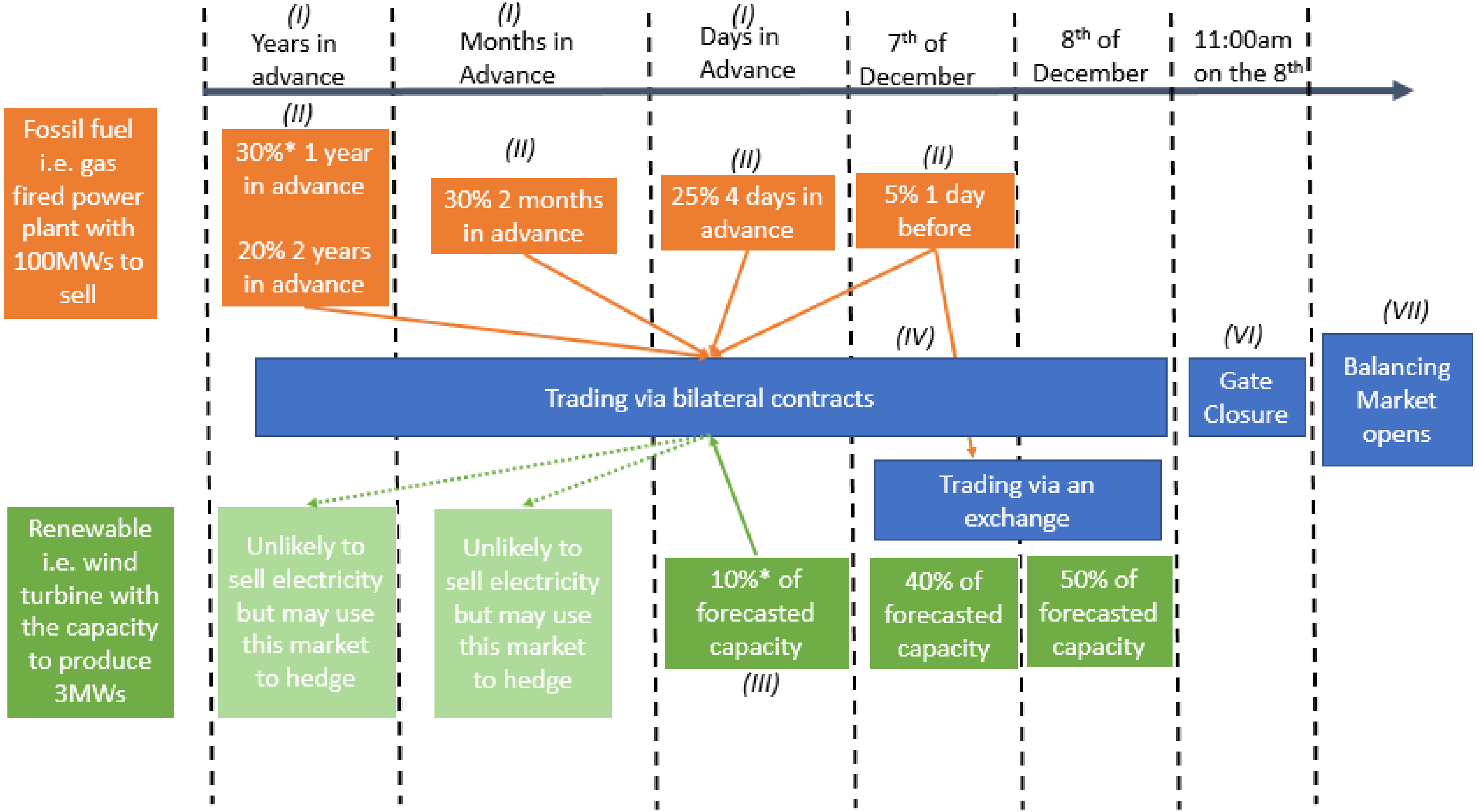

Figure 36 An illustration highlighting how a thermal generators position in the market would differ from a variable alternative. This figure does not incorporate contractual agreements such as CfDs and PPAs, but is based on merchant generation for illustrative purposes. All numbers are hypothetical.

Appendix two – Ancillary market products and developments

Table 28 Products procured within the ancillary market by national grid ESO. Note the '?' which indicate where information on this field is unknown, possibly due to this service being procured on a bilateral basis or the parameters of this product in question are still under consultation.

Products[1]	Brief description	Minimum size	Duration	Technologies	Payment structure	Contract means	Stack with the ancillary market?
Black start	The procedure used to restore power in the event of a total shutdown of the national electricity transmission system.	35-50MW	Provision of three sequential black starts i.e. starting without the requirement of external fuel sources.	CCGT / Coal / Biomass[2].	An availability payment (£/settlement period) Exercise payment (cover costs incurred during test runs) (£/MWh)	Bilateral	?
BM start up	The process of bringing up a generating unit to a state where it is capable of synchronising with the system within the balancing mechanism timescale.	?	Bespoke	States any balancing mechanism participants, but reviewing data suggests this is primarily gas and coal[3]	Start-up payment (£/hour) Hot standby payment (£/hour)	Bilateral	?

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[1] All products are listed at https://www.nationalgrideso.com/balancing-services/list-all-balancing-services

[2] National Grid ESO reviewing possibilities of securing black start from DER, via the coordination of several decentralised generators (National Grid ESO 2019i). This may include both technologies currently utilised within the balancing mechanism and non-balancing mechanism technologies. Together, these may include large/small wind generators, small solar, battery storage, electric vehicles, hydro and DSR.

[3] Plants identified using National Grid ESO's Sonar portal (National Grid ESO 2022).

Demand turn up	Encourages energy users and generators to increase demand or reduce generation at times of high renewable output and low national demand.	1MW (can be aggregated from 0.1MW)	2017 average: 3 hours and 34 minutes	Any technology which can increase demand, or reduce generation, including energy storage.	Availability payment Utilisation payment	Bilateral	No
Dynamic Containment	A new post-fault product aimed to rectify frequency deviations. This product will overtime replace tendered FFR services.	1MW(?)	?	Open to all. First tender saw two energy storage battery units accepted.	Accepted availability fee (£/MW/h)	Weekly auctions[1] (EPEXSPOT)	Intends to be.
Enhanced Frequency Response	Procures low frequency static and dynamic low how frequency	Currently under phase 2 trailing.			Availability payment	Weekly auction (EPEXSPOT)	?
Enhanced reactive power service	Procures the ability of either a plant, or apparatus, which can absorb reactive power which aren't required to provide ORPS (see below).	?	?	?	And/Or: Available capability price (£/MVar/hr) Synchronised capability price (£/MVar/hr) Utilisation price (£/MVarh)	Tenders held every six months	Yes
Fast Reserve	Provides rapid and reliable delivery of active power either through increasing output from generation or reducing consumption from demand sources	25MW	15 minutes of 25MW/minute	Any balancing mechanism or non-balancing mechanism technology. Typically (2017 mind) pumped	Availability fee (£/hour) Nomination fee (£/hour)	Monthly tender	Yes[2]

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[1] Aiming for daily auctions in the future.

[2] Units must be ready to respond to a fast reserve instruction at the start of each fast reserve window

				storage and hydro (Cornwall Insight 2018d)	Utilisation fee (£/MWh)		
Firm Frequency Response	Provides a route to market for those that can aid in frequency deviations. FFR: Dynamic frequency response - Continuously provided used to manage the normal second by second changes on the system FFR: Non-dynamic response - A discrete service triggered by a defined frequency deviation.	1MW	Primary response: sustained for a further 20 seconds Secondary response: sustained for 30 minutes High frequency response: sustained indefinitely	Any balancing mechanism or non-balancing mechanism technology which can meet the technical requirements including Tx and Dx connected generators, storage providers and aggregated DSR.	Availability fee (£/hour) Window initiation fee (£/window) Nomination fee (£/hour) Tendered winder revision fee (£/hour) Response energy fee (£/MWh)	Monthly tenders	?
Intertrips	An automatic control arrangement where generation may be reduced or disconnected following a system fault event.	N/A		Set up during the connection agreement / can be applied to existing connected units.	Arming payment (£/settlement period) Tripping fee (£/unit/trip)	Bilateral	?
Mandatory response services	Provision of an automatic change in active power output in response to a frequency change	N/A	Follows the same set up as firm frequency response.	Set up during the connection agreement / can be applied to existing connected units.	Holding payment (£/hour) Response energy payment (£/MWh)	Mandatory product	Yes
Obligatory reactive power	The provision of varying reactive power output.	N/A		Those signed up to the Grid Code i.e. can provide reactive power.	Utilisation payment (£/MVArh)	Mandatory product	

service (ORPS)							
Short Term Operating Reserve (STOR)	Provision of addition power to help manage actual demand when larger than forecasted.	3MW (increase or decrease and can be aggregated)	2 hours	Any balancing mechanism or non-balancing mechanism technology. Typically OCGT, hydro, DSR (Cornwall Insight 2018d)	Availability payment (£/MW/hr) Utilisation payment (£/MWh)	Tendered	No
Super SEL	Utilised to decrease the sum of the MW level of generators synchronised to the system though lowing the minimum generating level at a generator synchronised.	10MW (foot room)	Bilaterally agreed	CCGT, Coal/Biomass.	Enactment payment (£/MW/hr)	Bilateral	?
SO to SO	Procure services from another SO.	Bespoke to service.	Bilaterally agreed		Set out in tri-lateral contracts between SO and interconnector operators.		?
Transmission constraint management	A geographically defined product to aid in the undoing of constraints on the transmission network.	Based upon specific network requirements.	Bilaterally agreed		Utilisation fee (£/MWh) Fixed fee (£/settlement period)	Bilateral	

The requirements of the services procured in Table 28 reflect characteristics of the historical electricity mix which in turn hinders the ability for newer technologies and services to enter into these markets:

- Many of the ancillary services are procured bilaterally, Energy UK (2017) believes that this should be market based to maximise inclusiveness, ensuring services are procured at least cost with long term bilateral agreements should be avoided due to the exclusion of competition (Energy UK 2017).
- Accuse the products that are procured, and the criteria for procuring them, are fully reflective of the needs of the system as simply evolving from whichever services may be easily provided by large-scale transmission connected thermal plants (Energy UK 2017).
- Any new ancillary services framework should seek to capitalise on the value which all potential providers of services can bring, including new entrants, distributed plant, existing providers used in new innovative ways, demand response providers and nascent technologies such as battery storage, as well as the benefits provided by existing assets (Energy UK 2017).
- VRE, DSR and storage have significant potential to provide ancillary services – including frequency response such as primary, secondary and high response with synthetic inertia (Energy UK 2017).

National Grid ESO recognise that there are many barriers to integrating a higher proportion of VRE technologies into the ancillary markets, and are developing many of these markets to do so (Table 29). Whilst these will be welcomed by operators of VRE, there are still many hurdles which need to be reduced. For example, the fast reserve market has seen a reduction of the aggregated clip size from 50MWs to 25MWs (National Grid 2018; National Grid ESO 2019a). Whilst the lower clip sizes are suited to the increasingly decentralised electricity system, this still is a large clip size and thus still poses a barrier to many smaller technologies and services which could provide this product.

Table 29 A list of products within the ancillary markets which National Grid ESO acknowledge barriers to entry, and the developments within these design of these markets to address these.

Frequency Response		
Product(s)	**Barrier**	**Developments**
Mandatory market (dynamic primary, secondary and high) FFR (dynamic primary, secondary, high and low frequency static)	**High and low frequency response are procured as a bundled product** (National Grid ESO 2020n)**:** All generators must operate part-loaded, meaning below their maximum, in order to provide the headroom for both turn up and turn down. When operating part-loaded, all generators will experience a reduced revenue with well active power to sell. For generators with fuel i.e. CCGT, this loss is offset somewhat by the fuel saving. For intermittent technologies there is no fuel cost to be saved. In short, intermittent technologies operating part-loaded is a cost that may or may not be recovered depending on weather conditions. As such, providing frequency response as a bundle from intermittent generators tends to include a higher lost opportunity cost compared to their thermal counterpart.	National Grid ESO (National Grid ESO 2020n) are In the process of implementing a new settlement system for all balancing services to allow for more flexibility in settling different, new and non-standard products. splitting from LF to HF within the new dynamic products, essentially allowing wind farms to reserve foot room and reduce load whilst the frequency is high, hence the wind farm operator has no need of curtailing its output to part-load prior to the delivery of service.
Weekly auctions (Dynamic Low and high,	**Visibility of 'Power Available'** (National Grid ESO 2020n)**:** Changing weather patterns in real time create uncertainty for wind generators in providing frequency response.	National Grid ESO (National Grid ESO 2019g, 2020n) are: Intermittent generation operators already have access to on-site wind speed data and the operational characteristics of their assets. This data can be used

and low frequency static)	If a wind site part-loads to create headroom for low frequency response provision, or in responding to a high frequency event, the ESO control room has no visibility on the available active power that the site could provide if not responding to an action i.e. the ability for the wind site to increase their output depending on the weather patterns occurring at that time. In reality, the wind site could increase their output, but the ESO is not aware of the technical capabilities to do so. Without real time data from these wind sites to provide an assessment on the available headroom creates a risk to the safe and secure operation of the system.	to create the 'power available' signal which provides details on the power that should be available under the current on-site environmental conditions. Providing this signal to National Grid ESO control room will allow the in-team engineers to understand what the generator could be doing and therefore providing the confidence in instructing intermittent plants to provide frequency response whilst lessening the concerns of system security.
	Procurement timescales (National Grid ESO 2020n)**:** FFR monthly tender is too far ahead of delivery as weather patterns are not accurate this far out and creates a risk that the contracted obligations will not be met, and associated penalties will be issued.	National Grid ESO (National Grid ESO 2020n) are developing a single platform that will procure response services on the day ahead timescale. Within the current trial, generators can offer their available a from within day to seven days ahead allowing intermittent generators to bid in available at the timescale which best achieves their revenue against the risk of under-delivery as a result of changing weather.

Reserves		
Product(s)	**Barrier**	**Developments**
STOR Fast Reserve	**Procurement timescales** (National Grid ESO 2020n)**:** STOR has historically been procured via three yearly tenders covering a season i.e. 6-10-week period. Fast reserve has historically been procured via monthly tenders. These timescales are not suitable for intermittent generators.	API communication technology to allow intermittent technologies to offer STOR or fast reserve with utilisation only prices for upcoming STOR winders of 4-hour EFA blocks with a lead time of 60-90 minutes. Intention to move reserve products to a single platform at DAH timescales.
Restoration		
Product(s)	**Barrier**	**Developments**
Black Start	**Firmness of availability** (National Grid ESO 2020n)**:** This service requires a guarantee that the energy require, and at the required scale, is available at any time. Weather forecasting issues this is not 100% accurate, limiting their ability to offer this service under the current contractual arrangements.	National Grid ESO, alongside SP Energy Network and ENTI are working on a Network Innovation Competition project known as 'Distributed restart' (National Grid ESO 2019h). The project, running between January 2019-March 2022 is developing and aims to demonstrate the new approach to black start by DER sources including embedded hydro plants, wind turbines and solar panels.
	Size and location of assets (National Grid ESO 2020n)**:**	See above.

	Black start requires that the asset can energies in block sizes of 50MW to allow the DNO to be able to reconnect blocks of load. Also restricted to assets connected to the transmission network. As significant volumes of intermittent generation are connected to the distribution network, this requirement poses another barrier.	

Appendix three – Review of the 49 papers with proposals for electricity market reform

Please visit the following link for access: http://hdl.handle.net/10871/131099

Appendix four – Summary of respondents

Representative			
Academics	9	LEM representatives	2
Think tank	5	Trade associations	2
Incumbent energy supplier	3	DNO (DSO manager)	1
Consultants	3	European Energy regulator	1
ESO	3	SME energy supplier	1
BSC implementor	2	DER installer and optimiser	1
Energy economic regulator	2	Ex-MP	1
Electricity traders	2	Power Exchange representative	1
Government representatives	2		

Appendix five – Project brief for interviewees

Dear XXX,

My name is Thomas Pownall, and I am a PhD student at the University of Exeter in the Energy Policy Group. I am conducting a thesis on the current wholesale electricity market design in the UK and whether it is still fit for purpose in light of the changing electricity system.

The aim of this research is to design a new electricity market for the UK. This new market design will aim to facilitate a sustainable, cost effective and flexible system based on a high share of renewables and energy efficiency.

The second part of this research is focused on actual implementation of a new market design. This aspect is concerned with the actual transformation of the electricity market design and through what processes would alternative suggestions be adopted, or resisted by key institutions.

Throughout this interview I would like us to focus our conversation around three themes.

Theme 1: The future of the electricity system in your view

I would like to discuss:

- How do you envision the future electricity system?
- What you believe are the main goals for the future electricity system?
- Whether you believe there are factors constraining/enabling this change, and if so, what are they?
- Whether you believe there are factors constraining/enabling the achievement of these goals?

Theme 2: The need (or not) for implementing a new electricity market design

I would like to discuss:

- Whether you perceive recent events such as, but not limited to, Tempus and their legal case with the Capacity Market opening the debate on whether the current market design is fit for purpose?
- Any perceived constraints and enablers of altering current electricity market design
- The timeframe that you see any change occurring.

Theme 3: My proposal
In the final section, I will introduce the straw electricity market design and would like to discuss your thoughts on it.

If you wish to take a copy of this design away for further analysis, I can provide you with a physical copy.

Please feel free to contact me if you have any questions

Kind regards,

Thomas Pownall

Appendix six – The rationale behind the trade-offs within the proposed electricity market design

[Uploaded as separate PDF]

Appendix seven – Peer reviewed paper on the proposed electricity market design

Please visit the following link for access: https://www.mdpi.com/1996-1073/14/4/1124

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