Ordering change: the dynamics of energy transition and capitalist power

Research thesis

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The author of this thesis states that the research, including the collection, processing and presentation of data, addressing and comparing to previous research, etc., was done entirely in an honest way, as expected from scientific research that is conducted according to the ethical standards of the academic world. Also, reporting the research and its results in this thesis was done in an honest and complete manner, according to the same standards.

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Summary

The study of energy transition is crucial to confronting the risks of climate change. However, it lacks a methodical approach to understanding relations of capitalist power, energy regimes, and transitional dynamics. This study offers a systematic analysis of how business power shapes and controls socio-technical change under varying energy capture and power accumulation conditions.

The research's novel analytical perspective differentiates between four ideal-types of socio-technical pathways (structural change, stagnation, innovation, transformation) and relates these to changes in the breadth and depth of energy capture (exergy and energy conversion efficiency, respectively), and in the dominant business strategies which lead differential capital accumulation.

I use a mixed-method research approach: the quantitative study of social power dynamics as they are represented in differential prices is complemented by qualitative content analysis.

I explore two case studies: the historical process of transition to fossil-fuels and industrial capitalism in 19th century Britain; and the German *Energiewende* – the contemporary energy transition process that combines a decarbonization of the German electricity system with a reorganisation of the sector's ownership structure. To achieve a better understanding of socio-technical change pathways under capitalism, the undetermined *Energiewende* process is studied against the fulfilled transformative process of transition to fossil-fuels, in the context of their respective energy capture and differential accumulation conditions.

The quantitative analysis is based on new conceptual tools developed for this study. These tools integrate the differential analysis of physical data, used to study industrial change, with financial and accounting records data, used to study business processes. The German case study

also includes an analysis of in-depth interviews with business representatives from the German electricity sector.

The results suggest that rather than growth in energy capture, it is the ability to control the socio-technical process which is essential to the reproduction of capitalist power. As shown in the analysis of both, admittedly very different, case studies, it was only when dominant business formations (or their precursors) acquired a mechanism through which to shape and control processes of socio-technical change that these could be leveraged in differential capital accumulation.

The British case study analysis traces a period which I term the energy-core's seven good years of differential accumulation (1894-1900), during which, as rates of change in the transition to fossil-fuels began to decline, energy-intensive businesses began to supplement the control of output by early price-shaping mechanisms.

The *Energiewende* case study analysis shows how dominant electricity generation firms in Germany regained sectoral control by seizing the shrinking conventional generation capacity necessary to secure reliable electricity supply in the context of increasing variable (renewable) energy resource penetration. Thus, an implicit threat to future grid reliability gained German conventional electricity generation firms the leverage needed to increase differential prices and profits. This process coincides with spatial centralization, ownership concentration, and decreasing penetration rates of renewable energy resources in Germany.

The study sheds light on the relations between dominant business strategies, and the techno-physical attributes, scope, and pace of energy transition processes under capitalism.

List of Abbreviations

AEG - Alternative Electricity Generation. The category refers to the following primary energy sources and technologies: Onshore wind, Offshore wind, Solar PV, Geothermal, Biomass, Waste.

BDEW - The BDEW is a German industrial association representing firms in the energy and waterworks sectors.

CasP - Capital as Power. An approach to the study of capitalism which postulates that capital is not a productive/material entity, but a symbolic representation of power.

CEG - Conventional Electricity Generation. The category refers to the following primary energy sources and technologies: Hard coal, Lignite, Natural Gas, Nuclear, Oil, Mineral oil products, Hydro.

CFD - Contract of Difference. In electricity trading this refers to a subsidy model which ensures that negative deviations from a fixed reference price will be reimbursed (one-sided) or that both negative and positive deviations will be paid for (two-sided).

CHP - Combined Heat and Power. Technologies which generate both electricity and thermal energy at high efficiencies.

DER - Distributed Energy Resources. Distributed resources are generally small-scale, behind-the-meter, systems, located in proximity to customers (on-site), and providing both electric power services to consumers and grid stabilisation services to system operators/utilities.

EEG - Erneuerbare-Energien-Gesetz. The German Renewable Energy Sources Act which first came into force in 2000.

FinT - Feed in Tariff. A policy tool that sets a fixed, above-market price for renewable energy sourced electricity generation.

List of Abbreviations – continued

GW - Gigawatt. A unit of electric power. $1GW=10^9W$.

H2-ready power plants - Gas-fired power plants which are planned so that they can be converted to Hydrogen combustion in the future.

hp - Horsepower. A unit of measurement of power, usually in reference to the output of engines or motors. 1hp = 745.7 Watts

kW - kilowatt. A unit of electric power. 1kW=1000W.

kWh - kilowatt hour. A measure of electrical energy equal to 1 kW power sustained over a period of an hour.

MW - Megawatt. A unit of electric power. 1MW=1,000,000W

MWh - Megawatt hour. A measure of electrical energy equal to 1 MW power sustained over a period of an hour.

OTC - Over the Counter Trading. Transactions performed directly between two parties, without the supervision of an organized trading venue.

PV - Photovoltaic devices directly convert sunlight into electricity.

RES - Renewable Energy Source. Energy generated from naturally replenishable resources. The major types of renewable resources are Solar, Geothermal, Wind energy, Biomass, and Hydropower.

STS – Science and Technology Studies. An interdisciplinary field which studies relations of science, technology, and society.

TSO - Transmission System Operator. In the context of electricity networks, an entity responsible for transmitting electrical power from electricity generation plants to distribution system operators over a high voltage transmission grid, and other transmission network operation functions (i.e., balancing, maintenance, and development).

List of Abbreviations – continued

VER - Variable Energy Resource. Also known as intermittent energy resources, or inverter-based resources. These are typically renewable-based resources such as solar energy (e.g., wind turbines and solar PV). In contrast to conventional energy resources, which have a capacity value of almost 100%, power generation in VERs is dependent on environmental conditions so that their output varies over time and in accordance with them.

1. Introduction

This dissertation explores processes of energy transition under capitalism and lays the foundation for a more systematic approach to the empirical analysis of business power, energy systems, and socio-technical change.[3]

The study of energy transition is crucial to confronting the risks of climate change, and as such it has received increasing attention over the past three decades. A recognition of the urgency and historical uniqueness of the transitional challenges we face induced a rapid expansion in energy transition literature (Araújo, 2014).

Decarbonizing our global energy regime implies a transitional trajectory different from any which came before. Past energy transitions introduced primary sources and prime movers with higher energy and power densities, respectively (Smil, 2010b).[4] These transitions diversified the set of available sources while retaining the use of legacy fuels (York & Bell, 2019). A decarbonization of the global energy regime based on currently feasible technologies entails transitioning to primary sources and technologies characterised by lower energy densities and Energy Return on Energy Investment (EROI) rates,[5] and substituting these for conventional energy resources (Fix, 2021). The notion that economic growth and expansion could be sustained in tandem with an energy transition of this kind is highly questionable (Hickel et al., 2021), and there is strong evidence against the viability of absolute decoupling of economic

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[3] Socio-technical systems are defined as relatively stable and coherent sets of institutions, techniques, artefacts, rules, and practices which determine the social use of technologies and shape their development (Berkhout et al, 2005).

[4] *Primary energy* is found in the form of energy carriers which are "directly derived from a natural source" or the environment. These could include bituminous coal, crude oil, waste, solar radiation, wind or waterpower, to name a few examples (Olkuski et al., 2021: 503). The term *Prime movers* refers to devices that converts energy, e.g. engines, turbines, water wheels, etc. *Energy density* is measured as energy per unit of volume or mass, expressing the amount of energy stored in a given system, spatial unit, or substance. *Power density* is measured as power per volume, area, or mass, or change in energy per volume, area, or mass, expressing the rate at which the stored energy can be delivered (Smil, 2015).

[5] Energy return on investment (EROI) is a measure of the ratio between energy produced and energy used in its production.

growth from material and energetic resource consumption and environmental impacts (Barth, 2019).[6] Hence, the energy transitions to and from fossil-fuels, and related changes in societal energy capture,[7] do not only affect material production and consumption regimes, but the hierarchical social order itself.[8] Acknowledging the tensions and synergies between energy regimes and social power, and the pressing need for swift, effective, and radical change (Köhler, et al., 2019), leads to a "necessity to know what we are doing" which can only be fulfilled by "fusing political action with ongoing empirical and theoretical research" (Debailleul, Bichler & Nitzan, 2018: 54).

Nevertheless, energy transition literature currently lacks a methodical approach to understanding relations of capitalist power, energy regimes, and transitional dynamics (Feola, 2020). Socio-technical change theories have developed several approaches to addressing the issues of scope and pace in transition: to what extent does change affect the dominant structure, features and relations within a system; and whether the process is prolonged and incremental, or relatively swift and radical, respectively (Berkhout et al., 2003; Geels & Schot, 2007; Newell, 2018). The first point of departure for my research is that studying the ways in which socio-technical changes restructure social power, and vice versa, may give us a sense of the quality of transition at hand, and what scope of change it might harbour.

The second point of departure for my research is that capitalist technology has distinct features. According to Castoriadis (2024: 322, Footnote 33, 2003) the development of capitalist technology is driven by a constant class struggle over the shaping of, selection from, and curtailment of an exceptionally fertile and diverse stream of technical innovation. So, in order

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[6] *Coupling* refers to the proportionate co-evolution of two variables. *Decoupling* is the cessation of this trend. Absolute decoupling is a stronger term, meaning that the previously coupled variables now move in opposite directions. Relative decoupling is a weaker term, meaning that while variables still develop in direct proportion, but at different paces (Barth, 2019).

[7] The term *societal energy capture* refers to the full range of primary energy converted by humans into useful work as well as the energy demanded for this process at the level of society at large (Morris, 2013).

[8] For a discussion of different theoretical approaches to understanding the broad historical relations between growth in hierarchy and energy capture, see Footnote 47, and Section 2.2.5.

to study socio-technical change today and over the past two centuries, and to consider how "radical changes can occur in the way societal functions are fulfilled" (Köhler, et al., 2019:2), we should account for the specific forms of *capitalist* power and technology, rather than further developing a general theory of socio-technical change.

But this is easier said than done. To begin addressing these issues we need theoretical grounds and conceptual tools for the rigorous empirical study of the forms which social power takes under capitalism, and its relation to techno-physical systems and processes.

Hence, to start with, I build on the Capital as Power (CasP) approach's power theory of value.[9] Capitalism is a regime based on commodities, and the gradual commodification of everything. In it, pricing acts as a universal quantification system (Nitzan & Bichler, 2009). The CasP approach offers a theory of value in which prices are not understood as reflections of some underlying "real" quantity, but as rooted in power relations between owners. Capital itself is understood not as a productive entity (i.e., an aggregation of machines, infrastructure, factories, skill), but as "finance, and only finance" - a symbolic representation of power, as it is expressed in differential prices (Bichler & Nitzan, 2023: 116). This means that studying differential pecuniary measures enables us to study power relations.

However, the CasP approach is a theory of the ruling class, its formations and reproductive practices under the capitalist mode of power, not a totalizing social theory. It is a theory of the powers that be, and not of their potential alternatives. As such, it can be used to study power as it is exerted upon industry in transitional processes, but not the emergence of socio-technical innovation itself. The CasP approach understands capitalist power to be exerted over society at large,[10] yet it does not presume to theorise the indeterminately diverse social phenomena

[9] In political economy, initial attempts to articulate a theory of value stemmed from a preoccupation with the question of the source of income/profit, and thus, with distribution (Caporaso & Levine, 1992). Hence, the different theories of value in political economy strive to determine the factors and processes which condition the distribution of income, as expressed in the exchange value (prices) of goods and services.

[10] As the CasP approach defines capitalism as a mode of power rather than a mode of production and consumption (Nitzan & Bichler, 2009; 2023) capitalist power is understood to be exerted not only over the production process

themselves, but rather the power relations into which they are locked. In other words, industry, in CasP theory, is treated as what Cornelius Castoriadis termed *magma*, and has hitherto, perhaps wisely, not been theorised. For Castoriadis (1994), a magma is an indeterminable form from which social forms can be extracted but which is itself irreducible to them.[11] This means that industry, with the indefinite number of industrial formations, techniques, conceptions, and processes which could be extracted from it, has not been the object of CasP analysis in itself, but rather as a social phenomenon which gets capitalised, in which case the focus is on power relations.

Nevertheless, in this dissertation, so as to better understand the scope, pace and dynamics of socio-technical changes in energy systems under capitalism and thus to inform struggles to autonomously reshape them, I try to partially peer into the industrial magma, and the ways it is forcibly channelled through business.[12]

And so, I asked the following questions: What are the different forms of socio-technical change under capitalism?; and how are processes of socio-technical change related to changes in societal energy capture and social power accumulation?

As a first step towards answering these questions, I developed an analytical perspective on energy transitions which outlines relation between differential accumulation regimes, socio-

(that is, not only in the "economic" sphere), but over any social process that "bears on capitalization" (Nitzan & Bichler, 2015: 15).

[11] "A magma is that from which one can extract (or in which one can construct) an indefinite number of ensemblist organizations but which can never be reconstituted (ideally) by a (finite or infinite) ensemblist composition of these organizations" (Castoriadis, 1975: 343).

[12] Cornelius Castoriadis (1991) differentiates between two kinds of social logics - Autonomy and Heteronomy. Autonomy, from the Greek αυτονομία, stands for auto - self, nomos - law: subject to its own laws. Heteronomy, from the Greek ετερονομία, stands for hetero - other nomos - law: subject to the laws of another. Castoriadis understands every society to be self-created. Even so, not every society acknowledges this self-creation. The majority of societies, Castoriadis (1991: 128) tells us, are heteronomous in that they include the "institutionally established and sanctioned… representation of a source of the institution of society that only can be found outside of this society". In this sense, autonomous change would imply a process of systemic restructuring which follows and is subject to (always contestable) rules and rationales self-consciously instituted by those who undertake it. This as opposed to a process of change shaped and constrained by laws and logics whose sources are allegedly extrasocial, such as "the market", "the economy", "god", "ancestral law", etc.

technical pathways, and energy capture regimes.[13] This analytical perspective does not presume to decisively and fully describe, let alone explain or predict, business-industry dynamics in energy systems under capitalism. What I did attempt is to trace possible synergies and dissonances between developments in the breadth and depth of energy capture and differential accumulation strategies (as will be explained forthwith), claiming that these relations take part in shaping the scope and pace of socio-technical change in energy regimes under capitalism.

The analytical perspective differentiates between four ideal socio-technical pathway types, namely, structural change, stagnation, innovation, and transformation. It relates these socio-technical pathways to changes in the breadth and depth of energy capture (exergy and energy conversion efficiency, respectively), and in the dominant business strategies which lead differential accumulation.

The framework suggests that expansions in the breadth and depth of energy capture are coupled with external breadth (greenfield investment) and internal depth (cost cutting and productivity gains) pathways and related to transformative socio-technical changes in energy systems and in capitalist power accumulation itself. External depth (stagflation) and internal breadth (mergers and acquisitions) strategies are related to periods of increased path-dependency.

The research uses a mixed-method approach to trace the unique relations between social power and socio-technical change under capitalism. The quantitative study of complex social power dynamics as they are represented in differential prices is complemented by qualitative content

[13] According to CasP theory, differential accumulation is the driving logic behind capitalism. Capitalists are compelled to chase capital accumulation, yet accumulation as an absolute magnitude is meaningless. It acquires significance only when measured against a benchmark. To achieve differential accumulation, capitalist entities can engage in the strategic expansion in relative organizational size (expanding faster than others in controlling basic units of operation), in the strategic increase of relative earnings per employee (raising earnings per basic unit of operation faster than others), or both. When a certain strategic pathway generally dominates business' efforts to achieve differential accumulation it may be called a differential accumulation regime (Nitzan & Bichler, 2009).

analysis. This allowed me to delve into the specifics of how socio-technical systems are capitalized where quantitative data was lacking.

The quantitative analysis is based on novel conceptual tools developed for this study. These tools integrate the differential analysis of physical data, used to study industrial change, with financial and accounting records data, used to study business processes. The conceptual tools form the methodological lens through which I studied dominant business formations' (or their precursors') attempts to leverage techno-physical changes to increase their sectoral control, and the implications these might have for transitional pathways. I contend that to understand social power in energy transition, its pace, scope, and limits, we must combinedly study differential pecuniary data (representing business pathways), and physical data (representing industrial changes). The qualitative analysis includes content analysis of in-depth interviews.

The research is focused on two case studies of socio-technical change: the maturation of the transition to fossil-fuels and rise of industrial capitalism during the late 19th and early 20th centuries in Britain; and the German *Energiewende* (energy transition, or turnaround) - the energy transition currently in progress in Germany which combines the decarbonisation of the German electricity grid with a reorganisation of the sector's ownership structure.

The British case study represents a completed socio-technical transformation, and the ensuing long-term dynamics of change and stagnation, while the German case study represents a contemporary, volatile, and as of yet undetermined transitional process. The juxtaposed analysis of the two case studies harbours the potential to better understand relations of capitalist power and energy transition: the former marks the consolidation of capitalist power techniques and dominant capital formations alongside an unprecedented rise in energy capture resulting from the transition to fossil fuels;[14] the latter holds transformative potentials of decentralization and democratization which are contested by dominant capital formations working within a well-established capitalist regime.

The case study analysis uncovers two mirroring business-industry-energy processes. The first process regards the British case study: As rates of change in the transition to fossil-fuels began to decline in late 19th century Britain, control of output through physical breadth measures (i.e., growth in employment and use of primary energy) and physical depth measures (increased productivity per employee and energy input) were supplemented by an emergent price-setting mechanism.

The second process regards the German *Energiewende* case study: Following an initial destabilization, dominant electricity firms in Germany derived a mechanism through which to regain sectoral control, for the time being. The mechanism relies on the strategic control of shrinking conventional capacity necessary for securing reliable supply. Banking on a constrained perpetuation of renewable energy sources penetration, Fossil-fuels-based electricity generation firms engage in shaping and restricting the *Energiewende* process in accordance with their business interests.

Identifying these two mirroring processes enabled me to venture the argument that rather than growth in energy capture, it is the ability to control the socio-technical process which is essential to the reproduction of capitalist power. As shown in the analysis of both, admittedly very different, case studies, neither rampant growth nor the threat of significant decline in the breadth and depth of energy capture provided a stable and secure basis for differential accumulation. It was only when dominant capital (or nascent dominant capital) acquired a

[14] The term dominant capital refers to the coalition of leading corporations and government organs which support them (Nitzan & Bichler, 2009).

mechanism through which to shape and control processes of socio-technical change that these could be leveraged in differential accumulation.

The dissertation contributes to energy transition studies by introducing a conception of capitalist power and technique into the study of socio-technical change. Building on these concepts, I identify possible synergies and tensions between business-led differential accumulation regimes, and changes in energy capture regimes, and their relation to socio-technical pathways. In addition, the dissertation makes a small contribution to our understanding of the much debated but still illusive transitional process from feudalism to capitalism by tracing one of the earliest stable processes of differential accumulation in Britain. On the methodological level, I develop and employ new conceptual tools for the empirical study of capitalist power in transitioning energy systems. The tools combine techno-physical data and pecuniary (financial and accounting records data) analysis. Finally, in the course of the study I calculated several data series and variables which have hitherto been unavailable (see Appendix 4.4 and Appendix 5.5).

The remainder of this introduction is dedicated to a synopsis of the dissertation.

Chapter Two is a literature review. In it I present the different components of the relationships with which the study is concerned (socio-technical pathways, societal energy capture, and capitalist power) the ways in which the relations between them have hitherto been explored, and the open questions and new connections upon which the thesis's analytical perspective is based.

I begin by considering two approaches to the subject of social technique, and the social organization of production and reproduction. One is the Socio-technical systems approach, based on fields such as Science and Technology Studies, into which a consideration of social power had to be reintroduced as a means to explaining socio-technical regime resistance to change. The second approach can be traced back to the concept of Techné in Greek philosophy.

Power does not have to be brought back into this approach, it is already present, as technique is understood first and foremost as a social relation, a form of social organization of (collective) human creativity. I later introduce the CasP approach, with a special emphasis on the concepts of *strategic sabotage*, *differential profit,* and *differential accumulation regimes*, which play a central role in the study's analytical perspective and conceptual tools. I present a line of CasP research into issues of energy, capital, and power, and the ways in which my study endeavours to develop these efforts further. Finally, I consider other heterodox approaches to energy and the economy which I draw upon in my work, including biophysical economics and degrowth theory.[15]

Chapter Three is the methodology section. In it I lay out the research structure: the questions and hypotheses I set out with; the analytical perspective I developed, which identifies possible relations between energy capture regimes, capital accumulation regimes, and socio-technical pathways; the two case studies presented above - one British and historical, the other German and contemporary; the sources from which I derived quantitative data; the mixed methods approach through which I carried out the analysis; a detailed description of the quantitative measures and new conceptual tools which I developed; and a description of the qualitative content analysis of in-depth interviews I held with business representatives of the transitioning German electricity sector.

Chapter Four presents the results of the British case study analysis. I begin by tracing the techno-physical course of the transition to steam in British industry, outlining its different stages and focusing on the period of maturation during the turn of the 20th century, when the industrial transition to coal and steam power reached the asymptotes of change.

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[15] The terms orthodox and heterodox, when referring to economic theory, distinguish between mainstream (i.e., neo-classical) theories, and a host schools and approaches which rejects the assumptions of orthodox theories of the economy and offer alternative argumentation and conceptualizations.

Next, I explore the organizational and institutional changes which were set in motion during the second half of the 19th century, namely, business centralization, corporatization, and the larger use of credit. Following this, I present the heart of the findings, delving into an analysis of the differential performance of what I term the energy-core.[16] Finally, I consider the dynamics of power accumulation, energy capture, and sociotechnical change in the aftermath of the transition to fossil-fuels and during the consolidation of the 20th century's prevalent energy and social power regimes.

In this chapter I show how, as rates of techno-physical change began to decline, early price-shaping mechanisms began to supplement the control of output. During what I term the energy-core's seven good years of differential accumulation (1894-1900), the energy-core's differential productivity and growth in size were complemented by differential accumulation through differential pecuniary measures. I argue that the initial surge of the energy-core's differential accumulation at the turn of the 20th century created the basis for the second surge and consolidation of dominant capital during the interwar years of 1920-1938.

Chapter Five presents the results of the quantitative analysis of the German *Energiewende* case study. In this chapter I reveal the mechanism behind dominant German conventional electricity firms' regaining of sectoral control.

At the beginning of the chapter, I trace the differential financial recovery of conventional electricity generation firms which began in 2017. I show that this recovery was possible despite output loss on their behalf due to nuclear and coal decommissioning and due to a process of increasing differential internal depth for conventional electricity generation firms, which manifested in a rising conventional tariff alongside a declining alternative tariff. I argue that concerns over future challenges to reliable electricity supply pushed buyers (retailers and large

[16] The energy-core includes the era's energy intensive industries and the primary energy resource industries which sustained them, ferrous metals manufacturing, engineering commodities, and mining and quarrying, respectively.

industrial customers alike) to sign forward contracts, hedging against perceived future price hikes, and enabling conventional generators to appropriate higher revenues. The main beneficiaries of this process were big conventional electricity generation firms, who succeeded in concentrating conventional electricity sales into their hands. I argue that these dynamics influence the scope and pace of transition: as they unfold, renewable energy development displays increasing spatio-physical and ownership concentration trends, alongside decreasing penetration rates.

Chapter Six presents the qualitative content analysis of the in-depth interviews that I held with business representatives of the German electricity sector. The qualitative analysis draws on the results of the quantitative *Energiewende* case study analysis presented in Chapter Five. It explores issues and processes that were left undetermined by tracing in greater detail the business strategies deployed by dominant conventional electricity generation firms to boost their differential accumulation and income.

The analysis sheds light on dominant electricity firms' practice of shaping and obstructing the *Energiewende* - not too much so as to undermine the sociotechnical system of electricity generation, and not too little so as to lose the leverage which secures their differential profits. These firms strive to centralize new and existing dispatchable capacities under their hands. All the while, they differentially reduce the risks associated with the uncertainty of the coal-phase-out to position themselves to gain from any outcome of the process. In addition, I present a short analysis of redispatching prices that acts as a peephole to the ways in which dominant conventional electricity generation firms shape their revenue stream using over the counter trading.

Chapter Seven presents a concluding discussion of both case studies, each in itself and in relation to the other. I argue that, in the context of the German *Energiewende* in the electricity system, generation *control*, rather than output quantity, is the source of differential profits. In addition, subjugating the operation of a critical techno-physical nexus (the electricity grid) in a transitioning system to the logic of differential profit, bears consequences for the transitional process itself.

I next discuss the british case study, and the possibility that ferrous metals manufacturing businesses shaped differential prices by linking wage rates to output price rates. If this be the case, ferrous metals manufacturing businesses would have diverged from the general business conditions and embarked on a transition from price-takers to precursor price-makers, anticipating the business practices of mature capitalism. In addition, I consider the differences between growth in energy capture and increased control of energy capture, and their significance in reproducing hierarchical capitalist power formations.

Finally, *Chapter Eight* concludes the dissertation. In it I discuss its strengths, major contributions, weaknesses, and limitations, and suggest further research pathways.

2. Literature Review

This thesis is concerned with relations of socio-technical change in energy capture and social power accumulation under capitalism.[17] The literature review chapters introduce the different components of this relationship (socio-technical systems and change, societal energy capture, social power, the capitalist mode of power), the ways in which the relations between them have hitherto been explored, and the open questions and new connections upon which the thesis's theoretical framework is based (a presentation of which can be found in Section 3.5).

2.1 Energy and social technique

Raymond Williams (1983: 315) includes the word *technology* in his study of *keywords*, a set of pivotal words which make up the semantic fields of culture and society in English. He writes that, though in earlier usage the word *technology* refers to a broad concept of the "systematic study of the arts… or the terminology of a particular art", during the mid-19th century the word acquired its modern, narrower, meaning, becoming "fully specialized to the 'practical arts'". Williams (1983: 315) suggests that this modern usage stems from the "newly specialized sense of science" which distinguishes between "knowledge (science) and its practical application (technology), within the selected field". Thus, losing its significance as a form of systematic study, *technology* gained the meaning of a system of *techniques*, i.e., particular means and methods derived from the practical application of knowledge.

Hence, two distinct connotations of the term *technology* emerge. The first is based on the concept of *Techné* (referring to making or doing) in Greek philosophy, and the second on the

[17] *Socio-technical systems* are defined as relatively stable and coherent sets of institutions, techniques, artefacts, rules, and practices which determine the social use of technologies and shape their development (Berkhout et al, 2005). The term societal energy capture denotes the full range of primary energy converted by humans into useful energy as well as the energy demanded for this process, at the level of the society at large (Morris, 2013).

narrower, modern meaning of the word. Extending from these, two broad approaches to the subject of social technique, and the social organization of production and reproduction, can be traced. The following sections present these approaches with an emphasis on the social technique of energy capture.

2.1.1 Socio-technical regimes

The concept of socio-technical systems underpins the contemporary study of energy transition (Köhler, et al. 2019). This concept stems from research fields such as Science and Technology Studies (STS), Large Technical Systems, and Urban Political Ecology, for which networked infrastructures are of major concern (Mondstadt, 2009).

As suggested by its very name, the emergence of the discipline of STS was rooted in the separation between science as knowledge, and its practical application as technology. A separation which it has ever since been trying to transcend. In a definition which clearly represents this distinction, Sismondo (2017: 18) defines the academic discipline of STS as "focused on the interpretation of science and technology… developing sophisticated conceptual tools for exploring the development and stabilization of knowledge and artifacts". In the wake of WWII , an increasing awareness of relations between science and power induced several changes in the field of STS: An STS approach which actively engaged with public policy and science and engineering education was established in order to make "science and technology accountable to public interests" (Sismondo, 2017: 18); All the while, a broader disciplinary emphasis on the social aspects and implications of science and technology emerged (Spiegel-Rosing, 1977, Thorpe, 2017). The concept of social power[18] was used as a

[18] In this thesis the word *power* is used to denote both physical and social phenomena. In physics, power is defined as the rate at which energy is transferred or converted (or as the rate at which work is done, i.e., Worktime). Hence, P= Et , where *P* is power, *E* is energy, and *t* is time. When referring to *electric power*, power is expressed in joules per second, or watts, and is defined as the rate at which *moving charges* convert energy. From this basic definition of power, the general relation $P = VI$ (*P,* Power equals *V*, voltage times *I,* current) is devised (Priest,

theoretical glue to overcome the distinctions between scientific knowledge, its artifacts, and society, while maintaining them, albeit reservations that "science and technology are not sufficiently well defined and distinct" (Sismondo, 2004: 75). This resulted in a flourish of constructivist approaches in STS on the one hand, and horizontal complexity approaches such as Actor-Network-Theory on the other (Sismondo, 2004).[19]

The concept of *infrastructure* is central to the study of technology and society. Paul N. Edwards (2002:186) understands *infrastructure*, the large technological systems which form the basis of social functioning, to be a basic concept of Modernity, claiming that "To be modern is to live within and by means of infrastructures". He argues that the Modernist relation to infrastructure implies a sense of "stability" and assured reliance on its invisible workings. This relation to infrastructure is part of the Modernist "social contract to hold nature, society, and technology separate", and the aspiration (and pretension) to control the natural environment (Edwards, 2002:188).

Thinking about modern infrastructural systems, the Large Technical Systems theory was first formulated by Thomas P. Hughes (1983) in his seminal study of electricity systems in Europe and North America. The rise of environmental concerns and the gradual decay and impairment of aging infrastructural systems in the global North fostered a renewed interest in large infrastructure networks (Melosi, 2000). Large technical systems theory offered both a socio-

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2004). Social power is an altogether different concept, which, as is often the case in the social sciences, lacks a clear and widely agreed-upon definition. For the purpose of this thesis, I use Nitzan and Bichler's (2009:218), definition of social power as the "ability to shape and restructure the course of social reproduction at large", stressing that this ability is always manifested *against resistance* (Bichler & Nitzan, 2020).

[19] The constructivist approach within the theory of knowledge contends that human knowledge is constructed through social interactions, i.e., interaction with others. Thus, knowledge is understood to be socially situated and can only be interpreted as part of the social process of meaning construction (Schwandt, 1998).
A theoretical approach in sociology can be defined as *horizontal* (as opposed to vertical or hierarchical) when it emphasizes network-like interactions between the factors involved in social relationships, which are all understood to be endogenous and to exist on the same, single level. Kvachev (2020: 19) warns that approaches in which the complexity of a phenomenon is understood to imply horizontal interactions between the components of a system, harbour a *flat ontology* which ultimately excludes power from the explanation of social reality.

technical understanding of large infrastructure and production systems, and an analytical approach to sociotechnical change (Hughes, 1983; Van Der Vleuten, 2009).

A concern with infrastructure and social technique appears to resurface during times of crisis. Thus, during the second half of the 20th century a renewed focus on the role of energy in society arose in tandem with a biophysical conceptualization of society and of the economy, and a growing emphasis on complex systems and risk.[20] The 1970's oil crisis enhanced this trend, leading to the articulation of energy theories of value in environmental, biophysical, and steady-state economic theories (Daly, 1991; Fix, 2013). The institutions and infrastructures which facilitated the smooth workings of the global capitalist regime no longer seemed environmentally or politically reliable, and the prevailing theoretical dogmas seemed to fall short of explaining the crises. Drawing on biological systems conceptions, these new theoretical approaches defined human systems, from the level of the individual organism to that of the society, as open systems.

Open systems are dependent on importing and exporting energy and materials, changing in the course of this constant exchange with the natural environment (Von Bertalanffy, 1950). The realization that human society is dependent on in-flow of high grade, low entropy energy, and materials from the environment, and on the out-flow of low grade, high entropy heat, and waste back into it was absent from orthodox economic theory and coincided with a renewed interest in large technical systems. Socio-technical regimes may be understood as the institutionalised mode of this exchange between society and the environment.

The distinction between social and technical aspects of a system is rejected in the concept of the socio-technical system. Instead, socio-technical systems are defined as relatively stable and

[20] The term *biophysical* relates to energy and any other biological or physical resource (Hall & Klitgaard, 2018).

coherent sets of institutions, technologies, artefacts, and practices. These systems encompass a wide range of interaction between humans, technologies, and institutions and determine the social use of technologies and shape their development (Berkhout et al, 2005, Morgunova, 2021). Joerges (1988 :18-19) states that while it has become common practice to pay "lip service" to the idea that the technical "*is* social", in the study of large technical systems a distinction must be made between *technical* and other non-technical social phenomena. He defines *technical* as pertaining to "the concept of formal rationality, i.e. standardized methods of calculation on which routine actions can be based".

The socio-technical regime is defined as a stable and coherent set of institutions, practices, routines, and technologies, which have historically come to dominate the workings of a socio-technical system (Geels et al., 2017; Morgunova, 2021). The concept was articulated as part of the Multi-Level Perspective, which seeks to better describe and analyse transitional processes. The multi-level perspective presents a three-tiered structure, which includes the "macro" landscape level, the "meso" regime level, the "micro" niche level, and the relations between them as drivers of the stabilization and transformation of socio-technical systems (Geels et al., 2017; Morgunova, 2021).

Another aspect of a regime's stability is its "obduracy", which is manifested as path-dependency, inertia and resistance to change (Bulkeley et al., 2018). These phenomena are associated with characteristic "lock-in mechanisms", including sunk costs, economies of scale, sectoral interests, habitual use, and bureaucratization (Berkhout et al., 2003). Nevertheless, recent studies have pointed out that, under different circumstances, regime-level actors (i.e., incumbent firms and policy makers) may strategically engage in both restriction and promotion of innovation and change (Turnheim & Geels, 2019).

When examining path-dependency in urban sanitary infrastructure in the USA, Melosi (2000: 426) stresses the systemic character of path-dependency, which has less to do with the characteristics of specific technologies, and more with the wider social context of infrastructure design, construction and maintenance. He writes: “It was not so much that flawed technologies were chosen initially, but that systems were designed to be permanent, to resist change in order to justify their worth to the contemporary community”.

Following this line of argumentation, energy regimes can be defined as socio-technical regimes that shape socioeconomic energy flows; not only in terms of techno-physical conditions of conversion, but also in terms of socio-political conditions of decision-making regarding energy capture, distribution, and the ends and means of its use.

In energy transition literature, the concept of path-dependency has been used to address the ways in which fossil-fuel based sociotechnical systems reproduce themselves, creating various institutional, technological, and social “lock-ins” that complicate the process of decarbonization (Unruh, 2000). Critics warn of an over-deterministic view of path-dependency and stress the need to better theorize the emergence of new industries under capitalism (Goldstein et al., 2023; Krafft et al., 2014).

Early applications of multi-level perspective analysis have been criticised for their disproportionate emphasis on the micro niche level as the source of change and innovation (Berkhout et al., 2005; Turnheim & Geels, 2019). As will be elaborated upon in the following sections, the “meso” level of the regime, and its association with entrenchment, has served as an entrance point to a discussion of power in sustainability transition research (Köhler et al., 2019; Kuzemko, et al., 2017).

2.1.1.1 Regimes and transition

The energy transition literature offers various perspectives on the meaning of energy transition. Grubler et al. suggest that: “a transition is usefully defined as a change in the state of an energy system, as opposed to a change in an individual energy technology or fuel source” (Grubler et al., 2016: 18). “A change in the state of an energy system,” however, could take on many forms. The ambiguity comes to light when considering Vaclav Smil’s following lines: “Energy transitions – be they the shifts from dominant resources to new modes of supply… diffusion of new prime movers… or new final energy converters… are inherently protracted affairs that unfold across decades or generations” (Smil, 2010a:1). Smil views these processes as prolonged transitions. However, many distinctions may be found between the shift from the water wheel to coal-fed steam engines, and the ensuing fossil breakthrough (Malm, 2013), and the shift from incandescent to fluorescent lighting. The ambiguity of “transition” stems from the ambiguous scale of the regime itself. For instance, is an electric power regime to be understood at the level of primary energy source? A “general configuration of the power generation and distribution system” (Berkhout et al., 2004:54)? A shift from AC to DC transmission?[21]

Berkhout et al. (2003) suggest that transitions may be categorised into four “ideal types”, according to coordination at regime level (high/low and thus intended/unintended, respectively) and location of necessary resources (internal/external and thus superficial/deep, respectively). They suggest that when resources are internally available, transitions tend to be incremental and do not overturn structural relations, while externally resourced processes tend to be more radical.

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[21] The first electricity grids employed direct current (DC) technologies to transmit electricity. The introduction of alternating current (AC) technologies enabled the transmission of electricity over increasingly long distances and the growth and integration of grids (Hughes, 1983).

Grubler et al. (2016) distinguish between three types of transition: “Grand” transitions are pervasive and affect the system on multiple levels; Substitution is the displacement of a certain aspect of the system (a dominant energy carrier or technology) and its replacement by another, which requires little or no accommodation of the overall system; Diffusion is a prolonged, incremental process of the gradual adoption and integration of a certain technology within a given system. This categorization is similar to Geels and Schot’s (2007) concepts of substitution, transformation, reconfiguration, and de/re-alignment (Geels & Schot, 2007). Newell (2018: 41) uses the Gramscian term “transformismo” to differentiate between transformative change, which challenges existing structures, and its accommodation through discourses and policies of “green growth” and “climate compatible development” that shield the system from any serious threat that might be posed by such challenges.

Finally, Kanger and Schot (2018) develop the concept of *deep transition*, which understands energy transitions as features of social change at-large. They suggest that socio-technical regimes are the ultimate expression of a limited number of meta-rules that drive and constrain system evolution, while deep transitions are “a series of connected and sustained fundamental transformations of a wide range of socio-technical systems in a similar direction” (Kanger & Schot, 2018:1045).

The above theoretical sets address the issues of *scope* and *pace* in transition: to what extent does change affect the dominant structure, features and relations within a system (scope); and whether the process is prolonged and incremental, or relatively swift and radical (pace).

It may be argued that the socio-technical systems literature suffers a *truncation problem*, which stems from the "unavoidable arbitrariness of boundary definition” in relation to complex systems (Fix, 2013; Giampietro, et al., 2012: 39). Many socio-technical transition frameworks, acknowledging the complexity and interrelatedness of large socio-technical systems which encompass a broad range of social phenomena and are deeply embedded in them, end up trying to account for society at large, on very shaky empirical grounds. For instance, how does one account for the landscape level in the multi-level perspective approach (Geels, et al., 2017), or Kanger & Schot's (2018) *deep transitions* in an analytically coherent, rigorous, and empirically systematic way?

Studying the ways in which socio-technical changes restructure social power may give us a sense of the quality of the transition at hand, and what scope of change it might harbour. As will be elaborated on in the following sections, the Capital as Power approach understands social power to be exerted over society at large as well, encompassing an ever-growing range of socio-technical processes. Yet it also offers theoretical grounds and analytical tools for the rigorous empirical study of this power as it is universally and quantitatively represented in differential prices. Before developing these points further, I will present the ways in which power has hitherto been introduced in socio-technical transition literature.

2.1.1.2 Regimes and power

The study of social power in sociotechnical transition theory has gradually developed over the last two decades (Köhler et al., 2019; Kuzemko, et al., 2017).

Initially, power was brought in to explain regime resistance to change. Several accounts adopt *neo-Gramscian* concepts to address this phenomenon (Ford & Newell, 2021; Geels, 2014). In contrast to earlier literature, which focused on the conditions in which niche innovations penetrate "upwards" and set transitions in motion, these analyses concentrate on the ability of existing regime formations and incumbent actors to resist and block change (Geels, 2014). For Geels (2014), power is manifest in the hegemonic alliance of policymakers and incumbent firms. Not only do business and the state retain relations of mutual dependency (Kuzemco et al., 2017: Newell & Paterson, 1998), business has a structural advantage in that prevalent policy culture is dominated by neoliberal ideology and adapted to deal with large firms and experts, rather than with citizens.

Ford and Newell (2021) offer a more detailed account of power in maintaining regime stability. Drawing on neo-Gramscian concepts, they explore the ways in which business-government alliances exercise structural power to control and constrain transitional processes. Newell specifically understands transitions as conflictual processes, in which "competing social forces will contest the future organization of the economy in a carbon constrained world" (Newell, 2018: 27).

The "Neo-Gramscian" accounts hold hierarchical conceptions of power, as opposed to horizontal conceptions that create typologies of power (see for example Ahlborg, 2017; Avelino, 2017). These accounts follow the tradition of differentiation between domination and emancipation, as distinct qualities of power, and deliberately contest hierarchical conceptions of power (Pansardi, 2012).

Another perspective on social power in energy transitions deploys the concept of *market power*, which refers to the ability of a firm, or group of firms, to set prices by manipulating supply, demand, or both (DePamphilis, 2022). Most of these studies seek to uncover the so-called imperfect competition conditions prevalent in wholesale electricity markets. Hence, researchers have focused on the process of price formation in power exchange platforms.

Pham (2019) suggests that the market power of dominant electricity generation firms might be exercised by physically withholding capacity, and/or by financial withholding, which entails intentionally raising prices by bidding them up. Studying electricity markets in the USA, Borenstein et al. (1999) argued that during periods of high demand, dominant firms were able to strategically withhold supply to raise prices. They also expected that "extra-market sources of revenue – such as above-market contracts and capacity payments"[22] would become increasingly prominent in the electricity market (Borenstein & Bushnell, 2015: 26).

2.1.1.3 Economic cycles and technical innovation

Another approach which tries to trace the relations between technical and material phenomena and wider socio-economic phenomena stems from the Kondratieff-Schumpeter line of economic cycles literature. This approach tries to relate perceived broad cyclical price movements to a general theory of the "laws of motion" of underlying techno-physical developments and their relation to sectoral investment patterns. While Kondratieff argued that phenomena such as technological changes cannot be "properly regarded as exogenous", he declined to "render them endogenous", thus maintaining a theoretical distinction between monetary representation and physical reality (Rostow, 1975: 720). Schumpeter (1937: 166), building on Kondratieff's insights, and like Marx before him, tried to articulate a theory of capitalist growth ("economic evolution") "as a distinct process generated by the economic system itself", while maintaining the distinction between economic growth and monetary phenomena (Slim, 2019). Schumpeter (1939: 98) posited that "business cycles" follow the trajectory of major technological innovations which "tend to cluster".

Consequent studies of long-wave cycles in the economy and in technical inventions found significant correlation between the "initial stages of adopting new primary energies" and the inception of "major innovation waves" (Smil, 2017: 411). Using different terminology, researchers differentiate between *basic innovations* and *improvement innovations* in the conceptualization of these cycles of technical invention, innovation, and stagnation

[22] Above-market contracts are those in which income higher than that which would be received on the market is negotiated. Capacity payments are payments made to electricity producers for the maintenance of electricity generation capacity itself, rather than the power generated. These mechanisms will play a prominent role in the *Energiewende* case study analysis presented in Sections 5 and 6.

(Kleinknecht, 1992: 222; Mensch, 1979). Mensch (1979: 122) defines basic innovations as those that are “the source from which new products and services spring and in turn create new markets and new industrial branches to supply them".

Following Schumpeter’s notion of radical-innovation clustering, several theorists argue that new basic innovations are unevenly distributed over time and tend to appear in temporal proximity. Haustein (1992 :198) proceeds to define technical revolutions as consisting of “bunches of basic innovations that bring about changes in the value structure and in the profit rates of the whole production system”. While Carlota Perez (2010: 189) describes them as “a cluster of clusters or a system of systems” composed of interrelated and interdependent radical technological breakthroughs. The diffusion of these radical innovations has been characterized as resembling that of a logistic curve, including an initial phase of rapid growth, followed by a second phase of fast diffusion and sectoral growth, until full industrial deployment, and finally reaching maturation (Perez, 2002).

This line of explanation, which attempts to systematically relate technical and material processes (measured in prices) to cyclical economic phenomena, posits a regular inner logic to the process of technical innovation, linking it to a regular inner logic in business investment, driving a cyclical inner motion of capitalist growth. The following section explores an alternative approach with which to understand the dynamic nature of innovation under capitalism, placing it at the heart of the dynamics of power and resistance in capitalism.

2.1.2 Techné, technics, technique: the second route

A second route[23] through which to understand power and social technique, or the social organization of production and reproduction, can be traced back to the concept of *Techné* in

[23] Returning to Williams’ (1983) distinction between the broad and narrow connotations of the word *technology*, the first route which I presented is related to the distinction between science as knowledge, and technology as its

Greek philosophy. It is found in the works of Thorstein Veblen, Lewis Mumford, and Cornelius Castoriadis,[24] in which power does not have to be brought back in, it is already present, as technique is understood first and foremost as a social relation, a form of social organization of (collective) human creativity.

In his essay *Value, Equality, Justice, Politics: From Marx to Aristotle and from Aristotle to Us*, Castoriadis (2024) relate the concept of *techné* to that of *nomos*, situating them in homologous unsolved opposition to the concept of *phusis* in Aristotle's thought.[25] *Phusis* relates to "nature" and that which is "natural" while *nomos* relates to the law, to convention, to that which is instituted. *Techné* relates to craft, art, skill and dexterity, to that which is human-made and fabricated.[26] "Human affairs" are, in a sense, opposed to *phusis*, in that they involve *nomos* and *techné*, or "are, in a sense, *nomos* and *techné*" (Castoriadis, 2024: 425).

zNevertheless, reflects Castoriadis, while the Aristotelian distinction between the concepts of *phusis* and *techné* is essential, it is at the same time never absolute. *Techné* and *nomos* are both distinctly human and involve a creativity (*poiésis*) which potentially transforms what is, or *phusis*. This creative, radically transformative notion of human making arose during the classical era and is present in the Aristotelian conception of *techné* which "always cares about genesis, considers how to bring about what, in itself, could just as well be as not" (Castoriadis, 2024: 295). And humans are also *phusis*, thus *phusis* and *nomos/techné* are always engaged in

practical application (see Section 2.1). The second route relates to the wider understanding of *technology*, as will be elaborated upon in this section (Section 2.1.2).

[24] The interrelatedness of the writings of these three thinkers on subjects such as technique, creativity and power is not coincidental. Mumford was a student and colleague of Veblen, and Castoriadis was influenced by both (Mumford in particular) (Nitzan & Bichler, 2009; Curtis, 2024). Their combined body of work on the matter reads as a conscious extension, commentary, and reflection on the work of the one who came before them.

[25]"Aristotle, as is known, is thinking constantly with reference to *phusis*. And yet, the *phusis/nomos* opposition (like the homologous opposition of *phusis/techné*) remains internal to his thought, divides it, is not "surmounted" (Castoriadis, 2024: 369).

[26] While in Aristotle a clearer distinction between *epistêmê* (pertaining to knowledge) and *techné* (pertaining to craft, to making and doing) can be found (in relation to Plato and other, earlier and pre-Socratic thinkers for which the terms are nearly synonymous (Castoriadis, 2024b)), this distinction stays ambivalent, unstable and at times contradictory (Parry, 2024). All the while the concept of *techné* maintains an ambiguous relation to *poiêsis* (creation) (Castoriadis, 2024).

an insurmountable tension.[27] In addition, and contrary to the Modern distinction between science and technology, knowledge and practice, in classical Greek philosophy there is no clear distinction, let alone opposition, between *techné* (craft, skill, dexterity) and *epistemé* (knowledge). Thus, there is no inherent distinction between the social practice, (i.e., the ways and means), the social definition of needs and objectives they are supposed to fulfil, and the social reflection on their consequences (Tulley, 2008). Thus, these processes/acts of definition and reflection are always political (as is the Aristotelian human *phusis*), always involving *nomos* (law, convention, institution).

In what follows, I will present the ideas of each of these three thinkers relevant to the matter (i.e., Veblen, Mumford, and Castoriadis) and engage with them.

2.1.2.1 Thorstein Veblen and business control of industry

Veblen's definition of *industry* combines both *techné* and *epistemé* in the ongoing collective systemization and social production. In his series of essays *The Engineers and the Price System,* Veblen (1921: 28) writes: "The state of the industrial art is a joint stock of knowledge derived from past experience and is held and passed on as an indivisible possession of the community at large". Hence, Veblen understands industry to be a collective venture rooted in cooperation and the integration of social activity and knowledge, to form a "systematic organisation of production and the *reasoned* application of knowledge" (Nitzan & Bichler, 2009:219, my emphasis; Veblen, 1923; Veblen, 1908).

Industry draws on the collective, historical "technological heritage" of a society which is common (indivisible) and accumulative (passed on joint stock) by nature. It gives meaning to

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[27] In Castoriadis' (2024: 426) words: "Aristotle has to separate *phusis* and *techné* —and he has to not separate them absolutely, for then there would no longer be for *techné* and its products any status, any ontological site; were *techné* not anchored in "imitation" or "perfection" of *phusis*, it would be nothing. Insofar as *techné* essentially exceeds nature, it remains unassimilable within Aristotelian ontology (and within all inherited ontology)".

and thus coordinates the amassment of bio-physical, technical and energetic components which are "brought within the sweep of the community's *knowledge of ways and means*" (Veblen 1908: 329, my emphasis).

The phrase *knowledge of ways and means* emphasises the collective, epistemological connotations of the term *industry*, which is not the sum of tools, procedures, and practices, but an inherently collective understanding of their integration, organization and consequences. This point is elaborated upon by Castoriadis (1984) who stresses that the technical object has no meaning outside of a set of mental and physical practices (which Castoriadis terms "dexterities") and other material creations, which in turn acquire their full significance only within a whole social complex.[28]

In addition, Veblen defines *industry* as the *rational* organization of production directed towards enhancing livelihood and collective well-being. In this sense, in its ideal form it differs from other, traditional, forms of organization of production, both in goals and in logical underpinnings.[29] Moreover, the growing interdependence of different components of the industrial processes, that are in principle open to participation (Veblen, 1923:64), drives an overarching synchronization and standardisation of production processes and their objectives, and requires a "solidarity" in industrial management (Veblen, 1935: 17).[30]

Yet Veblen was not interested solely in the manifestation of human creativity in industry, but also in its relationship to power.

For Veblen, *business* is an institution of power. *Business* does not produce, and it is not concerned with well-being. Rather, it is concerned with profit, and therefore with distribution.

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[28] To illustrate, a semiconductor would be meaningless (or acquire a very different meaning than it holds today) in the hands of a medieval blacksmith; a work contract would be meaningless in a slave society; practices of commons management lose their meaning under the regime of radical privatization; and early quasi-industrial techniques have no "social application" before the appearance of the urban proletariat (Castoriadis, 1984: 246).

[29] To illustrate, while ritualistic, or purely traditional elements might prevail in earlier, craft-based forms of the social organization of production, these are alien to *industry*, which strives to rationally streamline the productive process (Guth, 2021).

[30] Note that Veblen uses the term *solidarity* which refers to unity and agreement rather than *centralization*.

As such it stands in opposition to industry, although the two are deeply related. Business, as practice and institution, lays claim to industrial and productive processes and thus increasingly brings industry under its control, substituting the collective enhancement and definition of well-being with the sectorial quest for differential accumulation. This is ultimately expressed in the institution of absentee ownership which once and for all severed the connection between owners and their interests, and industry and collective social interests (Nitzan & Bichler, 2009; Veblen, 1923).

Veblen formulated the conflicting concepts of business and industry in a specific historical context: on the one hand, the institution of the joint stock company which enhanced the distinction between business and industry in the form of absentee ownership and the increasing separation between ownership and production; on the other hand, what he saw as a "rebellion" of young American engineers against the domination of industry by big business, particularly in the utilities sector (Layton, 1962:67).

The dialectical relations between business power and industry, and whether these can be defined as such, are of particular interest to me in this study. According to Veblen, industry is an inherently collective and open endeavour and as such open to ongoing inter-subjective constitution and definition of what is good and desirable - what can be imagined and what is considered worthy of achieving.[31] It is what Castoriadis (2024: 307) terms "the endlessly ongoing… impossible translation of desire into a realizable aim".

Industry denotes the *rationalisation* of human action and organisation of production and should not be confused with production or craftsmanship per se. It emerged together with the institutions of capitalist power, and they have been intertwined forthwith (Castoriadis, 2024). Business power might restrict industrial creativity, but it is also involved in driving it, carving

[31] Note that inter-subjectivity does not imply autonomy - it could equally be enforced, imposed or decided upon democratically (Nitzan & Bichler, 2009:226). Moreover, industry might play an equally effective part in the creation of weapons of mass destruction as in the creation of equitable infrastructure.

out and enhancing certain practices and interactions. Modes of power might also come to be entwined with certain states of *industry*, which is historically shaped in relation to power. In other words, *industry* in its historical manifestation, is not a separate, autonomous institution.[32] It has no democratic organizational structure of its own, but one that is intertwined with business management, while *industry*'s autonomy remains, at best, a potentiality. *Industry* is not only intertwined with business at present, the two also emerged together, and so we do not even have a concrete historical example of industry operating without the effects of business upon it.

Returning to Castoriadis' notion of industry as translation between human desires and realizable aims,[33] it can be argued that translation is a form of transformation which necessarily exceeds and diverges from its source yet is also irreducibly related to it. In other words, there is a dialectical relation between human creativity and its potentials, and forms of institutionalized organization which direct and enable its realization. It is dialectical in that it involves a translation between different social logics (desires and potentials into institutionalized, normative order). When the necessary translation is done between two *conflicting* social logics, we enter the sphere of power, a form of domineering translation which forces the expression of one logic through the other. The relation between *business* and *industry*, and thus the historical manifestation of *industry,* is such a domineering translation.[34] The *business* logic of differential accumulation and power channels the collective, inclusive and well-being-oriented logic of *industry* in a relation of ongoing tension.

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[32] Notwithstanding Veblen's (1921: 138-143) dreamed of a "soviet of technicians" which would manage and plan the industrial process according to a shared set of scientific values.

[33] "Industry is not only "the open book of human faculties"; it is also the endlessly ongoing text for the impossible translation of desire into a realizable aim" (Castoriadis, 2024: 307).

[34] Note that while *industry* necessarily involves translation it does not necessarily involve domination through translation. Veblen's "soviet of technicians" is precisely an effort in imagining a form of institutionalized translation which does not include the subjugation of one social logic to another.

These dialectical relations of domineering translation differ from other forms of power relations. Translation is never complete; it exceeds its source and at the same time cannot exhaust it. In this sense, *business* control of industry is never complete, and *sabotage*, its special form of power exertion, is never absolute. As will be elaborated upon in Section 2.2.4, unlike former modes of power in which control of social production might take a more direct form, *sabotage* denotes a dialectical relation in which effective control is never hermetic.

2.1.2.2 Lewis Mumford and technics as social organization

Following Veblen's emphasis on the relations between human creativity and social power, Lewis Mumford formulated his own line of thought and set of concepts. Mumford does not understand power as merely exerted upon human creativity and production, but as a form of technology in itself. Returning to the interrelated concepts of *techné* and *epistemé,* Mumford offers a critique of modern technology as "*techné* divorced from *epistemé*" (Tulley, 2008: 98). Technology for Mumford is not merely the practical methods and structures which constitute the ways in which humans apply their knowledge to manipulate and transform of the natural world, but the ways in which society reorganizes itself around this continuous creative flux. *Technics* are as much the organized ways in which people interact between themselves and with their environment (i.e., the organization of social relations) as they are specific methods of manipulation of the natural world. Mumford formulates this understanding of technology within a set of related concepts, the *megamachine*, *polytechnics* and *monotechnics*, *authoritarian technics* and *democratic technics*.

The concept of the *megamachine* denotes not a material machine but rather an "invisible machine", the social and bureaucratic structure which enables the organization, control and the division of labour of masses of humans. Thus, the first machine, according to Mumford, was not a physical construct, but a form of social organization. Appearing first in the despotic civilizations dating five millennia ago, this novel and far-reaching social technique, which increasingly presided over all domains of social existence, made it possible for ruling classes to coordinate and subjugate huge workforces in immense and complex endeavours such as the pyramids of Egypt and Mesoamerica.[35] This technique of social organization not only enabled new forms of human creation but shaped and restricted them as well. Mumford distinguishes between two kinds of "technics" - in the sense of the organization of social relations - *polytechnics* and *monotechnics*. The first is "broadly life-oriented, not work-centred or power-centred" (Mumford, 1967: 9), while the second is oriented towards the accumulation, maintenance and expansion of (centralized) power.

Moreover, while in early civilizations the *megamachine* enhanced the power of a personalized ruler and ruling class (e.g., the pharaoh, the emperor), in modern times the object and centre of authority is the system itself (Mumford, 1964). Which brings us to the distinction between *authoritarian* and *democratic technics*. According to Mumford, *Democratic technics* date back to the earliest, primordial use of tools. It is the "small scale method of production… remaining under the *active direction* of the craftsman or the farmer… This democratic technic has underpinned and firmly supported every historic culture until our own day…" (Mumford, 1964: 2-3, emphasis added). This form of technology is directed and organized by the community, and its objectives are the life-sustaining and enhancing objectives of the community. *Authoritarian technics*, appearing around the 4th millennium BCE under the institution of kingship, is a system in which "a new configuration of technical invention, scientific observation, and centralized political control that gave rise to the peculiar mode of life" (Mumford, 1967: 3).

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[35] The *megamachine* as a form of social organization changed the social production both quantitatively and qualitatively: "By operating as a single mechanical unit of specialized, subdivided, interlocking parts" writes Mumford (2003: 348), "the 100,000 men who worked on that pyramid could generate ten thousand horsepower". "These work armies and military armies raised the ceiling of human achievement: the first in mass construction, the second in mass destruction, both on a scale hitherto inconceivable" (Mumford, 1964: 3).

Thus, the differences between *democratic* and *authoritarian technics* are not merely in scale and capacity but significantly in the centre of authority and inner logics of social creation. According to Mumford, this is all the truer in our day and age when authority no longer lies in a visible personality but within the system itself with which we erroneously identify our interests and wellbeing. This is due to the dialectic nature of the relations between society and technology - not only do mono, or authoritarian technics enable new forms of social creation, but they become the objective of creation itself (as opposed to life), designing and restricting it to match an ever-growing demand for power.[36]

2.1.2.3 Cornelius Castoriadis and capitalist technology

It seems that Castoriadis (2024: 308) builds directly on Mumford's insights when he writes: "of all "techniques," the most important one is social organization itself, the most powerful apparatus ever created by man is the regulated network of social relations". He defines social technique as "the "rationalization" of relationships among men as such "rationalization" is constituted by the society under consideration" (Castoriadis, 2024: 309). This indicates that for Castoriadis, technology is primarily a form of social organization, which involves the rationalization of social relations, i.e. the positing, through social institutions, of a common underlying logic. It is also the self-creation of any given society, taking different forms in different societies across historical space and time. We cannot speak of technology determining social significations[37] or the reverse but should rather examine the ways in which these qualities

[36] This observation is similar to the distinction made in the previous section, between a direct control, restriction, and direction of human creativity and production, and the dialectic form of business power and control through sabotage.

[37] For Castoriadis, social being is a state of self-creation. *Social Imaginary Significations (SIS)* define the extent of what can be imagined, and the values attached to it (Castoriadis, 1975; Martin, 2019). These SIS are the temporary stabilisation in institutions of the "magma of social significations". The social magma is "the totality of representations s/he [a social subject, T.L] is capable of making" (Castoriadis, 1994: 124). Even though the social magma is the source of an infinity of possible social significations and their institutions, it is not reducible to these organisations. This is because of the radically creative aspect of *Creative Imagination*. Castoriadis sees the *Creative Imagination* as indeterminable. It constitutes the social ability to create new imaginary significations - a radically new idea of the world which differentiates one society from another (Castoriadis, 1991).

come together at specific time-spaces to make a society's "real-rational" - "that which society posits as imposing itself upon society" (Castoriadis, 2024: 305). That is, what comes to constitute the boundaries and inner structure of its reason, be it the animistic or magical frameworks of early/primaeval cultures or the scientific rationalism of the late modern era. Technique is always a novel human creation. An object, process, or method of making-doing (*techné*) which transforms the "natural" world (*phusis*) and creates a new idea or concept which can be reproduced. As such, it can also transform the social, even as it is conditioned by social significations.[38] Castoriadis distinguishes between *technics* and *technology*, which he defines as a "historically-extant", "selected "spectrum" of techniques" (Curtis, 2024: lx) pertaining to specific societies. In accordance with this assertion, Castoriadis was especially concerned with what could constitute capitalist technology.[39]

Castoriadis characterises capitalist technology as unprecedentedly ample, marked by an abundance and diversity of innovation: "for each "need," for each productive process, it develops not an object or a technique but a vast gamut of objects and techniques" (Castoriadis, 2024: 322).[40] Thus, the selection between these creative potentials of production, the promotion of some techniques and the simultaneous repression of others, lies at the heart of the dynamics of power and resistance under capitalism. In this sense, power and industry become enmeshed - technology becomes an instrument and stake of class struggle. The selection, development or

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[38] Castoriadis (2024: 305) writes: "what renders possible not only technique but any kind of making/doing is the fact that brute reality is not frozen, that it includes immense interstices allowing one to move, assemble, alter, and divide; and also, that man can insert himself as real cause within the flux of the real".

[39] This is not to say that he was seeking a relation in which "the hand-mill gives you society with the feudal lord; the steam-mill, society with the industrial capitalist" (Marx, 1957: 122), but rather that he was interested in the technology which was part of the capitalist real-rational.

[40] In fact, Castoriadis (2024: 322) defines capitalist technology as "everywhere dense." Here he is referring to a concept in the mathematical branch of topology, in which a subset A of a topological space X is said to be dense in X if "every point of X is a point or a limit point of A" (Steen & Seebach, 1978: 7). Thus, mathematically, the term "real-rational" itself denotes a subset (rational numbers) which is everywhere dense in the space of real numbers. Castoriadis says that capitalist technology is an everywhere dense subset of the vast range of innovation and possible developments under capitalism. Thus, selection (and restriction) becomes a central process of the "concretization" of capitalist technology (the dense subset of a gamut of innovation), which is "at once instrument of and stake in the class struggle" (Castoriadis, 2024: 322). This is in fact the definition of the dialectical exertion of *business power* over *industry* through *sabotage*, as opposed to direct control of the productive process.

curtailment of techniques is driven by conflicting logics and embodies social struggles. Capitalist technology is never "neutral" (Castoriadis, 2024). Industrial path-dependency and innovation are part of the dialectics of power and sociotechnical change in capitalism. Change and inertia are shaped by power struggles that unfold within a given industrial terrain. Castoriadis does not tell us why capitalist technology is so fertile. Yet the answer may lie in his claim that the two central significations of Western Modernity are rational mastery and autonomy. The logical underpinnings of rational mastery and the modern rationality and autonomy which characterise *industry* have much in common, albeit a few fundamental differences which account for the tension which arises when *industry* is channelled through *business*.

2.2 The Capital as Power approach

Capital as Power (CasP) is a theory of capitalism which "understands capitalism to be a mode of power, and not a mode of production or consumption" (Bichler & Nitzan, 2020:2; Nitzan & Bichler, 2009; McMahon, 2015:30). It offers not a totalizing and exhaustive theory of society, but rather, a theory of the ruling class and the ways in which power appears and is organized under what Bichler and Nitzan term the *capitalist mode of power*, or the *state of capital* (Nitzan & Bichler, 2009).

While the CasP approach may offer a means of analysing and critiquing capitalism as a mode of power, it does not presume to explain society as a whole, and therefore does not also pretend to foresee dynamics of change.[41] The social, being irreducible to dynamics of power, is not determined in and through these dynamics alone, though capitalised power strives to expand into, preside over and delimit (i.e. capitalise) not only more and more of certain social and

[41] "Capitalization and productivity/creativity are two distinct processes, each with its own separate 'logic'. The destructive clash of these two processes is the engine of the capitalist dialectic, but the dialectic itself cannot be understood with one common language" (Nitzan & Bichler, 2009: 20).

biophysical phenomena but also more and more kinds of phenomena (Nitzan & Bichler, 2009). An alternative to the mode of power is in essence the social creation of a radically new social order and as such cannot stem entirely from that which it seeks to replace.

And so, following the observation that power is overtly ubiquitous in capitalism, yet insufficiently theoretically defined in both orthodox and heterodox political economic theory,[42] the CasP approach places power at the heart of its theory of capital and capitalism, defining it as a mode of power and articulating a power theory of value.

Bichler and Nitzan (2009:7) begin by asking what is capital? And answer, rejecting the economics/politics dichotomy, that capital is not to be understood as a productive economic entity but rather as a "symbolic representation of power" in itself.

Similarly, capitalism is not defined as a mode of production but as a mode of power. Following Mumford (1967), Nitzan and Bichler (2009) describe modes of power as forms of social organisation which are based primarily upon social (rather than material) technologies and directed at reshaping society (rather than nature) with the exceptional incentive of exerting power over society for the sake of power itself. Preceded by the feudal mode of power, the capitalist mode of power first emerged during the 14th century, with the institution of private ownership at its core (Nitzan & Bichler, 2009; Di Muzio, 2021).

As a mode of power, capitalism is unique in three significant senses: 1. It harbours a single, universal and quantifiable measure of power - capitalization; 2. Capitalization functions as an operational symbol; 3. It is driven by differential accumulation - not merely the conservation of differential advantage but its augmentation. These features also account for the exceptional

[42] The terms *orthodox* and *heterodox*, when referring to economic theory, distinguish between mainstream (i.e., neo-classical) theories, and a host schools and approaches which rejects the assumptions of orthodox theories of the economy and offer alternative argumentation and conceptualizations. CasP is considered a heterodox approach.

dynamism and versatility of the state of capital.[43] The following sections develop these three claims.

2.2.1 Capitalization - a universal and quantifiable measure of power

Capitalism is a regime based on commodities, and the commodification of everything, and in which pricing acts as a universal quantification system. CasP offers a theory of value in which monetary prices are not understood as proportionate to some underlying "real" quantity, but as rooted in power relations between owners. Relative prices, and capitalization, are a measure of these power relations. According to Bichler and Nitzan (2020: 15, my emphasis), "capitalist power – which includes every form of power that bears on accumulation – is manifested in and reduced to the *quantity of capital*", which "appears as capitalization".

Capitalization is a mathematical algorithm - it discounts risk adjusted expected future earnings to present value. Capitalization acts as a measure of organized control exerted over the social process as a whole: politics, society, culture, and social reproduction (Nitzan & Bichler, 2009). What is assessed and measured in capitalization is the broad social, rather than material, ability to generate income by shaping and controlling social processes. The capitalization formula is defined as follows:

$$K_t = \frac{E \cdot H}{\delta \cdot r_c}$$

Equation 1: Capitalization formula

[43] "In our view, Marx was correct to stress the dialectical imperative of technical change… Over the longer haul, capitalists indeed find themselves compelled – and in turn force their society – to constantly revolutionize the pattern of social reproduction. They continually 'invest' in having industry develop for them new methods and products and in expanding their capacity to produce them. Yet all of this they do in the expectation of adequate differential returns, and differential returns are possible only through restriction" (Nitzan & Bichler, 2009: 232-233). In contrast to the Marxist perspective which defines the dialectic process as internal to the mode of production, the CasP approach emphasized the conflicting logics of creativity/livelihood and power/domination which, in the necessary translation of the first through the latter, form a dialectic dynamism.

where capitalization at a given time Kt equals expected future earnings (the product of actual earnings E and the hype coefficient H), divided by the product of the risk coefficient δ and the normal rate of return rc. Thus, capitalization is the discounting of expected future earnings to present value and is based on four "elementary particles": earnings, hype, risk, and the normal rate of return. Transitional changes, as they affect these variables, are figured into the capitalization process. In this sense, a CasP based analysis of power in energy transition goes further than a study of market power in that differential power accumulation is understood to be the goal of capitalist entities, and capitalization is understood to represent the degree of comprehensive exertion of power over the sociotechnical transition process.

2.2.2 Capitalization - an operational symbol

Capitalization is not merely a measure of power. It can also be defined as an operational symbol, i.e. a formal system in which signification results from "some operation according to some rules" (Martin, 2019: 6). This operational symbol is both generative and "autocatalytic" and closed in that problems created by these operations are addressed using further operations based on the same logic (Martin, 2019:16). And so, capital is not merely a measure of power but also a generative mechanism enabling the creation of "formations" which in turn reinforce that very same ability (Martin, 2019: 4). The "self-reflexive use of power" forms the basis of the differential and expansionary attributes of capital accumulation. Power is, by definition, accumulated in relation to that of others. Yet within a generative, self-reflective system, this power must always be augmented in relation to that of others - not only more but increasing. Hence differential, as opposed to absolute, accumulation.

In addition, the "architecture of power" tends to gradually draw more and more members and spheres of society into its workings. Members are drawn into differential accumulation precisely because it is differential. Because opting out would mean loss of relative power and not immunity to it, while all of society's resources tend to turn into "means for those conflicts" (Martin, 2019: 4). This is manifest in what Bichler and Nitzan (2009: 158) term "the capitalization of everything".

2.2.3 Differential accumulation, breadth and depth

Differential accumulation is the driving logic behind capitalism. Capitalists are compelled to chase capital accumulation, yet accumulation as an absolute magnitude is meaningless. It acquires significance only when measured against a benchmark. Thus, it is the differentials that matter, the "difference between the growth rate of [one's, T.L.[44]] own assets, and that of the average" (Bichler & Nitzan, 2002:11).

Differential profit (the degree to which one's profits exceed the average) is a central component of differential accumulation. I will present it in detail, as it will later support the conceptual tools used in the empirical analysis.

Bichler and Nitzan (2002) define profit as:

$$P = breadth \cdot depth = E \cdot P/E$$

Equation 2: Profit formula

where *P* is profit, and *E* is the number of employees, and *P/E* is profit per employee.

Profit is a consequence of both *depth* and *breadth*. *Breadth* refers to the size of the organization, i.e., the number of basic units controlled by the capitalist entity. *Depth* refers to the elemental power of the organization, i.e., the earnings per unit of organization. Bichler and Nitzan use employees to represent the basic unit of organization, as they are concerned with the exercise of power by people over people (Bichler & Nitzan, 2023). Capitalist organizations may

[44] Clarifications by the author are brought within square brackets, and followed by the author's initials, T.L.

accumulate by expanding in size, thus directly controlling more units of organization (breadth), or by extracting higher earnings per unit of organization, thus indirectly exerting power over society as a whole (depth), or by a combination of both.

Yet, as with accumulation, profit, breadth, and depth acquire meaning only in relation to the performance of others. Hence, differential breadth is defined as the strategic expansion in relative organizational size, and differential depth is the strategic increase of relative earnings per employee (Nitzan & Bichler, 2009).

At any given moment in time, this can be expressed as:

$$DP = dif.breadth \cdot dif.depth = \frac{E_1}{E_2} \cdot \frac{P/E_1}{P/E_2}$$

Equation 3: Differential profit

Here, *DP* is differential profit, *E1/E2* is differential employment and *P/E1 / P/E2* is differential profit per employee.

The concept of differential accumulation regimes stems from the understanding that accumulation is not necessarily the result of growth. Rather, dominant capital firms may alternate between different strategic paths to achieve differential accumulation. Firms may opt for *differential breadth* (expanding faster than others in basic units of organization), *differential depth* (raising earnings per basic unit of organization faster than others), or "by some combination of the two" (Nitzan & Bichler, 2009: 329). These paths can be further categorized as *internal* or *external.* The four generic paths are summarized in Table 1.

Table 1: Differential accumulation regimes

	External	***Internal***
Breadth	Greenfield	Mergers & Acquisitions
Depth	Stagflation	Cost cutting

Reproduced from: Nitzan & Bichler, 2009: 329.

External breadth hinges on differential greenfield development, i.e. building new capacity and hiring faster than others.

Internal breadth is based on expanding in size through mergers and acquisitions, i.e., acquiring existing capacity, and "inter-firm labour mobility" (Nitzan & Bichler, 2009: 330). This achieves the double goal of expanding in size and eliminating competition.

Internal depth involves cost-cutting to make operations more cost effective faster than other organizations.

External depth derives from stagflation, i.e., combined inflation and stagnation in production. Bichler and Nitzan argue that "Dominant capital, to the extent that it acts in concert, can benefit from higher prices, since, up to a point, the relative gain in earnings per unit outweighs the relative decline in volume" (Nitzan & Bichler, 2009: 330).

They claim that breadth and depth regimes tend to move counter-cyclically, with internal breadth (mergers and acquisitions) and external depth (stagflation) constituting the most effective paths to achieve differential accumulation. This is due both to the drawbacks of greenfield development (external breadth), like the threat of excess capacity and the negative effect on prices, and hence on depth; and to the difficulty of leveraging cost-cutting (internal depth) to beat the average, i.e., the difficulty of protecting technological innovations and controlling input prices.

2.2.4 Strategic Sabotage and Dominant Capital

The objective of differential accumulation is outperforming one's opponents and "beating the average". Hence, sabotaging production can become as instrumental to differential accumulation as production itself. Bichler and Nitzan define *strategic sabotage* as the ability to "restrict, limit and inhibit the autonomy of those with less or no power," for the purpose of increasing profit (Bichler & Nitzan, 2020: 2). This framing is based on Thorstein Veblen's (1923) distinction between business and industry, presented in Section 2.1.2.1, and on his use of the term business *sabotage* to denote a "conscious withdrawal of efficiency" administered by business (Veblen, 1921: 15), using a "strategy of delay, restriction, hindrance… obstruction" of production (Veblen, 1921: 5-6).

Bichler and Nitzan's conception of *strategic sabotage* emphasizes both the wider manifestation of *sabotage*, whose application is not restricted to the economic sphere of production alone, and the significance of the *strategic* aspect: the "appropriate" degree of sabotage must be applied in order to sustain and augment power, while not creating social or systemic instability which could disrupt the power structure, and without undermining its own socio-material basis (Bichler & Nitzan, 2023).

The state in CasP theory is seen as inseparable from capital, as is corporate from government power (Nitzan & Bichler, 2009). It is itself a capitalized entity in a dual sense: governmental bonds are a capitalization of the state's power to tax and form the basis of global finance; and governmental action bears upon capital accumulation thus getting figured into capitalization (Nitzan & Bichler, 2009). Di Muzio (2016) points out that governmental bond markets form the basis of global finance, with private bondholders receiving interest payments from revenues generated by governmental practices, thus rendering the state itself a capitalized entity.

Ongoing processes of differential accumulation create what Nitzan and Bichler (2009) term *dominant capital*, tightly intertwined and organized clusters of leading corporations and state organs, which control and shape society in the course of sustaining and augmenting their power over it.

2.2.5 Energy and CasP

This section pursues a line of CasP research into issues of energy, capital, and power. In this line of research, core concepts and measures of CasP are employed to analyse trends and transformations in the social technique of energy capture and its relation to social power.

First, the distinction between politics and the economy, with regards to the energy sector, is challenged. Bichler and Nitzan (2002) for example base their analysis of energy crises in the Middle East on the concepts of differential accumulation and differential inflation. They argue that energy conflicts generate differential inflation,[45] which in turn boosts the differential accumulation of dominant energy firms. This fuels a self-reinforcing cycle as the revenues are then used to acquire weapons, which augments the differential accumulation of dominant arms industry firms and enables the next round of bloodshed-cum-differential-accumulation. In this analysis, war is understood to be a form of sabotage that drives differential inflation, and thus differential accumulation processes - not an external shock, but part and parcel of the internal workings of power that get capitalized - i.e., added to calculations that determine the relative value of capital.

[45] Oil prices rising faster than other commodities.

Second, the general relations between energy capture and social form are theorized. Blair Fix's (2015; 2017; 2019) work explores the broad relation between historical rates of energy conversion and the accumulation of social power and its organization in hierarchical forms. His perspective and empirical approach challenge the basic assumptions of neoclassical theory regarding economic growth. The neoclassical perspective understands growth in terms of "utility," namely that a growing economy supposedly implies growth in the "amount" of utility or "wellbeing" produced and available within a given nation state at a given period (Alexander, 2012).[46] Fix, however, understands and measures growth in biophysical, and power-based terms, namely energy capture, and the degree of social hierarchy, respectively.

Both biophysical and power related dimensions are excluded from neoclassical analysis, in which the biophysical is taken for granted and unaccounted for, and power is deemed external to the economic system. Fix's study establishes a "three-way link between profit, hierarchy, and growth" (Fix, 2015: 26). These findings raise the question of the nature of the relations between the social technique of energy capture and social form. Exploring the relationship between energy capture and social form is crucial to considering energy transition and understanding the socio-material dynamics that shape these systems and drive or hinder change (Fix, 2021). In this context, Fix (2021) identifies three theoretical approaches by which to understand these relations: materialist, wasteful and functional.[47]

Finally, the relations between change and power in the energy sector are explored. Tim DiMuzio (2012) attempts to discern the relations between energy transition processes, their

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[46] These studies typically use measures such as "real GDP", which denotes inflation adjusted goods and services produced at a certain period, to study growth.

[47] The materialist approach contends that the growth of energy drives the growth of hierarchy as an unintended outcome. As production of surplus grows with energy capture, elites appear through the disproportionate appropriation of this surplus (Fix, 2021). The functional approach suggests that hierarchical organization is functionally necessary to achieve higher energy capture. Thus, hierarchy is a historical-evolutionary solution to the biophysical constraints of human cognition in organizing and cooperating in large groups (Fix, 2021). The wasteful approach contends that the growth of hierarchy drives a wasteful growth in energy capture and is in fact dependent upon it. In this sense, it is "wasted" on the sabotage necessary to reproduce power and withstand the resistance it inevitably evokes (Bichler & Nitzan, 2020; Fix, 2021, Fix et al., 2019).

potential, and the capitalization of conventional energy firms. The rationale behind DiMuzio's endeavour is that differential capitalization represents the differential power of social entities, and that this power is leveraged in shaping and reshaping social reproduction (in this case, towards the persistence of energy-intensive growth). DiMuzio studies the power of fossil-capital through the differential capitalization of conventional energy firms, and of "alternative" energy firms, as representatives of a potentially successive energy regime. In doing so, he tries to gauge capitalists' perceptions of the future, their degree of confidence in the persistence of the current energy regime, and the extent of the efforts they will put into sustaining it. In the same vein, Brett Christophers (2022) argues that an analysis of the actions, valuation, and investment trajectories of dominant capital indicates that fossil fuels are yet to be forsaken, and are still viewed as profitable, i.e., "sustainable". The declining price of renewable technologies does not imply an increase in differential expected earnings associated with them.

In this study, I continue the CasP line of inquiry presented above, and its use of the concepts and measures of differential accumulation, capitalization, and the relations between social power, biophysical limits, and social technique. I develop these ideas further by advancing a theoretical framework for the empirical study of the dynamics of power, as they play out in the relations between the business-regulation nexus and the industry in energy transition processes. CasP theory is, self-admittedly, a theory of capitalized power, not its negation (though it assumes the latter). It is a theory of the powers that be, and not of their potential alternatives. It can only theorize about power as it is exerted upon industry in transitional processes, and less about the emergence of socio-technical innovations themselves.

2.3 Other heterodox approaches to energy and the economy

Another theoretical field that is significant to any study of energy transitions that seeks to address issues of socio-technical change, social power, and energy, is the critique of neoclassical growth theory with regards to the relations between energy and the economy. Biophysical, environmental, steady-state, and entropy economics all contest the dominant perspective of orthodox, and many heterodox, economic theories which downplay, or utterly ignore, the biophysical underpinnings of socio-economic systems (Daly, 2014; Hall & Klitgaard, 2018; Smith & Smith, 1996).

These economic theories apply the laws of thermodynamics[48] to the study of economic systems, understanding the economy to be an open system, namely a system that exchanges both energy and matter with the environment (Smith & Smith, 1996). System thinking is central to these approaches, as it emphasizes the irreducibility of the whole to its components and the complexity arising from the system's internal and external dynamics (King, 2021). Defining the economy as an open system implies the inherent disequilibrium of growth-oriented economic systems which are dependent on the environment as source and sink. Moreover, the concept of "throughput", in the form of energy and material inputs, heat and waste outputs, and entropy, becomes central to the understanding of socio-economic systems.

More specifically, energy (as the capacity to do work) is considered the basis of biological, and therefore social, activity (Daly, 2014). Useful work can be defined as "performing activity in the real world that necessitates physical exertion" (King, 2021: 28). The transfer of energy enables work. Thus, the significance of energy is understood to be much greater than its share of GDP (as assumed in neoclassical theory). It is understood to be the conditioning factor without which no economic activity can take place (Keen et al., 2019). Consequently, energy capture, and particularly the explosion in the rate and scale of energy conversion associated

[48] According to the law of conversion of energy, while energy can be transferred, it cannot be created or destroyed. Entropy represents the quantity of "high grade" energy (i.e., energy available for conversion into work, as opposed to heat) within a system. It is also a measure of randomness, as it is assumed that the creation and sustenance of order requires work and thus, energy inputs (Smith & Smith, 1996).

with the transition of fossil fuels, is considered the main driver of the phantastic rates of growth and exceptional dynamism associated with capitalism (DiMuzio, 2015).

Biophysical and spatial attributes of the environment are conditioning and limiting factors of economic systems and their growth (Hall and Klitgaard, 2018). Consequently, degrowth approaches reject the notions of "green growth" and absolute decoupling of economic output from material throughput and argue instead that downscaling the economy is necessary to achieving equitable sustainability (Barth, 2019; Kallis et al., 2018). Consequently, degrowth theory argues against the notion that economic growth could be sustained in tandem with an energy transition to primary sources and technologies characterised by lower energy densities (Mastini et al., 2021).

Blair Fix adds a dimension of social power to these insights. He argues that "external (resource) constraints can describe the long-run behaviour of the economy, but internal (social) constraints dominate the short-run" (Fix, 2015: 113-114). These internal constraints are not to be understood as anomalies to an otherwise equilibrium-forming economic system, but as the inherent features of a power-driven social order which is itself spatio-physically conditioned.

All approaches presented above agree that energy is paramount to economic growth. Fix (2015) goes as far as to suggest using energy itself as a growth metric. To do so, we must first be able to measure energy consumption. Understanding that energy extraction itself requires energy, the measure of Energy Return On Investment (EROI) is used to quantify the ratio of primary energy produced to energy required for extraction (King, 2021). The concept of *useful work* attempts to account for further energy losses and requirements in the primary and secondary conversion to end-use energy. Ayres and Warr (2009) developed an initial measure of the annual average energy conversion efficiencies of five generalised end-use energy categories. The energy consumed annually by each end-use category, multiplied by the respective annual average energy conversion efficiency, gives us an approximation of *useful work* performed by a system. This is but one example of several approaches to the measurement of societal exergy (Sousa et al., 2017).[49]

The insights presented in this section form the theoretical basis for the integration of spatio-physical analysis into the study of energy transition. Andreas Malm (2013) incorporates both spatio-physical and power-related factors into his analysis of the transition from water to steam in 19th century British cotton industry. Malm contends that, contrary to claims that the transition was driven by scarcity, it was in fact class struggle that shaped and drove the transition. He argues that the advantages of steam lay not in coal's relative abundance or cost-effectiveness, but in steam's spatial and temporal flexibility, which enabled industrialists to more effectively control and discipline labour. Accounting for the spatio-physical conditions of powering the British cotton industry during the period of transition, Malm explores the broad class interests (as opposed to interests of a specific incumbent actor) that drove socio-technical change.

Others have also stressed the historical link between the energy transition to fossil-fuels and resulting confidence in the availability of cheap power, and the maturation of capitalism. Timothy Mitchell argues that fossil-fuel-based infrastructures formed the material basis for the rise of joint stock corporations, as they offered a large scale and relatively secure stream of future earnings which could be discounted as present profits for their absentee owners (Abourahme & Jabary-Salamanca, 2016). Moreover, neoclassical ideology assisted in de-politicising the new fossil-fuel-based energy regime. This regime was delinked from any "collective, recognizably human decision" (Pendakis, 2017:96), any form of autonomous

[49] Ayres and Warr use the term exergy rather than energy. Exergy denotes the potential of a system to do work. It is defined as "the maximum amount of work that can theoretically be recovered from a system as it approaches equilibrium with its surroundings reversibly" (Ayres & Wart, 2009: 78). As this is not a technical paper, I use the more generally known concept of energy

deliberation, and coupled with the heteronomous[50] order of "supply and demand", which obscures socio-political decisions and legitimises them as reflections of an imagined market equilibrium.

In what follows, I offer a new analytical perspective on relations of capitalist power, energy regimes, and transitional dynamics. Using this perspective, I empirically revisit the coupled transition to fossil-fuels and maturation of capitalism, explore contemporary decarbonization processes, and the relations between these two historical instances.

[50] Cornelius Castoriadis (1991) differentiates between two kinds of social logics - Autonomy and Heteronomy. Autonomy, from the Greek αυτονομία, stands for auto - self, nomos - law: subject to its own laws. Heteronomy, from the Greek ετερονομία, stands for hetero - other nomos - law: subject to the laws of another. Castoriadis understands every society to be self-created. Even so, not every society acknowledges this self-creation. The majority of societies, Castoriadis (1991: 128) tells us, are heteronomous in that they include the "institutionally established and sanctioned… representation of a source of the institution of society that only can be found outside of this society". Needless to say, this heteronomous representation is itself self-instituted, yet self-institution is denied and obscured in heteronomous societies.
Autonomy, on the other hand, is a reflexive social acknowledgement of self-institution (Castoriadis, 1991).

3. Methodology

3.1 Justification

The causes and risks associated with climate change, and the consequently imperative "energy transition", are at the heart of contemporary political and professional concerns worldwide (Araújo, 2014; Creutzig et al., 2014). Never before has the need to actively bring about a change in the ways and means of societal energy capture been so widely discussed (UNDP, 2024).[51] Yet, transitioning away from humanity's increasingly global "fossil fuel addiction" (Huber, 2013) implies a transitional trajectory different from any which came before.

The trajectory of past energy transitions was directed at primary sources and prime movers with higher energy and power densities, respectively (Smil, 2010b). Moreover, past transitions have tended to diversify the set of primary sources, adding to the overall energy capture while retaining the use of legacy fuels, rather than fully replacing them (York & Bell, 2019). Using existing and currently feasible technologies, decarbonization entails both a transition to primary sources and technologies characterised by lower energy densities and EROI[52] rates, and the displacement of (already depleting) conventional energy resources (Fix, 2021). The notion that economic growth could be sustained in tandem with an energy transition of this kind is highly questionable (Hickel et al., 2021). Hence, the contemporary energy transition might bear consequences not only for material production regimes, but also for the prevalent social order itself.[53] Nevertheless, energy transition literature currently lacks a methodical

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[51] Societal energy capture denotes the full range of primary energy converted by humans into useful energy as well as the energy demanded for this process at the level of the society at large (Morris, 2013).

[52] Energy return on investment (EROI) is a measure of the ratio between energy produced and energy used in its production.

[53] Historically, the maturation of capitalism and the rise of global capital have been bound up with fossil-fuels. Not only is global capital's growth regime historically founded on an underlying fossil-fuelled energy regime, but the energy sector also itself has historically evolved into dominant capital groups throughout the 20th century (Hall

approach to understanding relations of capitalist power, energy regimes, and transitional dynamics (Feola, 2020). Due to the urgency of the contemporary transitional challenge at hand, a recognition of its historical uniqueness, and the need to conceptualize how "radical changes can occur in the way societal functions are fulfilled" (Köhler, et al., 2019:2), sustainability transition literature has rapidly expanded over the past decade. The conflictual aspects of socio-technical transitions have prompted theorists to introduce the idea of power into energy transition theory (Köhler et al., 2019). Building on CasP theory, this dissertation offers a systematic analysis of how business power shapes and controls socio-technical change under varying energy capture and power accumulation conditions.

Many prominent theories of socio-technical transition differentiate processes according to the scope and pace of change they harbour (Geels & Schot, 2007; Grubler et al., 2016; Kanger & Schot, 2018). Yet, the understanding of capitalism and its relation to energy regimes is underdeveloped (Feola, 2020), and business-industry-regulation dynamics of socio-technical changes in energy-related sectors have yet to be systematically researched from a CasP perspective. This perspective may be essential to the understanding of both the mutual effects of power and energy transition, and the scope and depth of transitional processes. An understanding which is crucial in answering the question posed by Köhler, et al. (2019) regarding how to bring about radical change in prevalent energy regimes and may inform current transitional efforts.

& Klitgaard, 2018). While this does not mean that capitalism is *dependent* on fossil-fuels, there has been an historical contingency between mature capitalism and the fossil-fuel-based energy regime.

3.2 Goals

Two distinct yet related motivations drive the current study. One is theoretical and methodological, and the other is empirical.

On the theoretical level, the research seeks to develop an analytical perspective for the study of energy transition and social power which integrates both an understanding of capitalist power relations and a consideration of societal energy capture. It offers a taxonomy of socio-technical change as it relates to energy capture regimes and differential accumulation regimes. In addition, from the perspective of CasP theory, the research seeks to develop both a better understanding of the maturation of the capitalist mode of power, and a methodical exploration of industrial change and business power.

On the methodological level, the research seeks to develop a set of sector-specific measures for the study of socio-technical change under varying energy capture and capital accumulation conditions.

The analytical perspective and methodological tools are expected to aid the empirical study of contemporary renewable-energy-based decarbonization processes, to achieve a better understanding of unfolding energy transitions and the dynamics of decentralisation, decarbonization and social power therein (see Section 3.5). I will use the approach developed in this research to analyse a prominent contemporary case of national energy transition - the German *Energiewende* in the electricity sector. In addition, I will use the analytical perspective to empirically explore the historical transition to fossil-fuels in Britain. I seek to better understand the contingency between the maturation of capitalism and the shift to fossil-fuels, and business-industry relations therein.

3.3 Questions

The following questions stem from the study's goals and motivations:

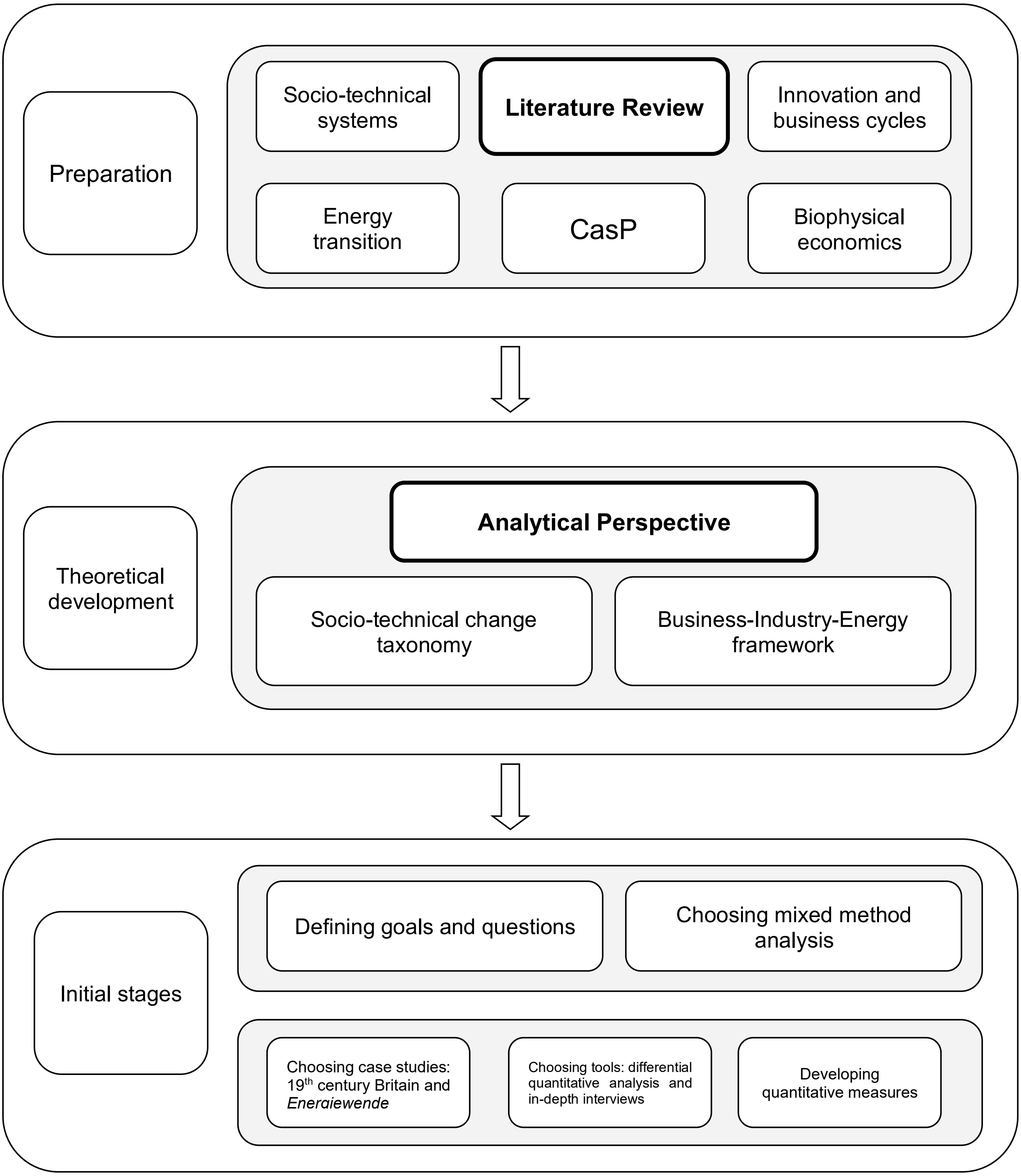
1. What are the different forms of socio-technical change under capitalism?
2. How are processes of socio-technical change related to changes in societal energy capture and social power accumulation?
3. How do social power accumulation strategies relate to socio-technical change pathways?

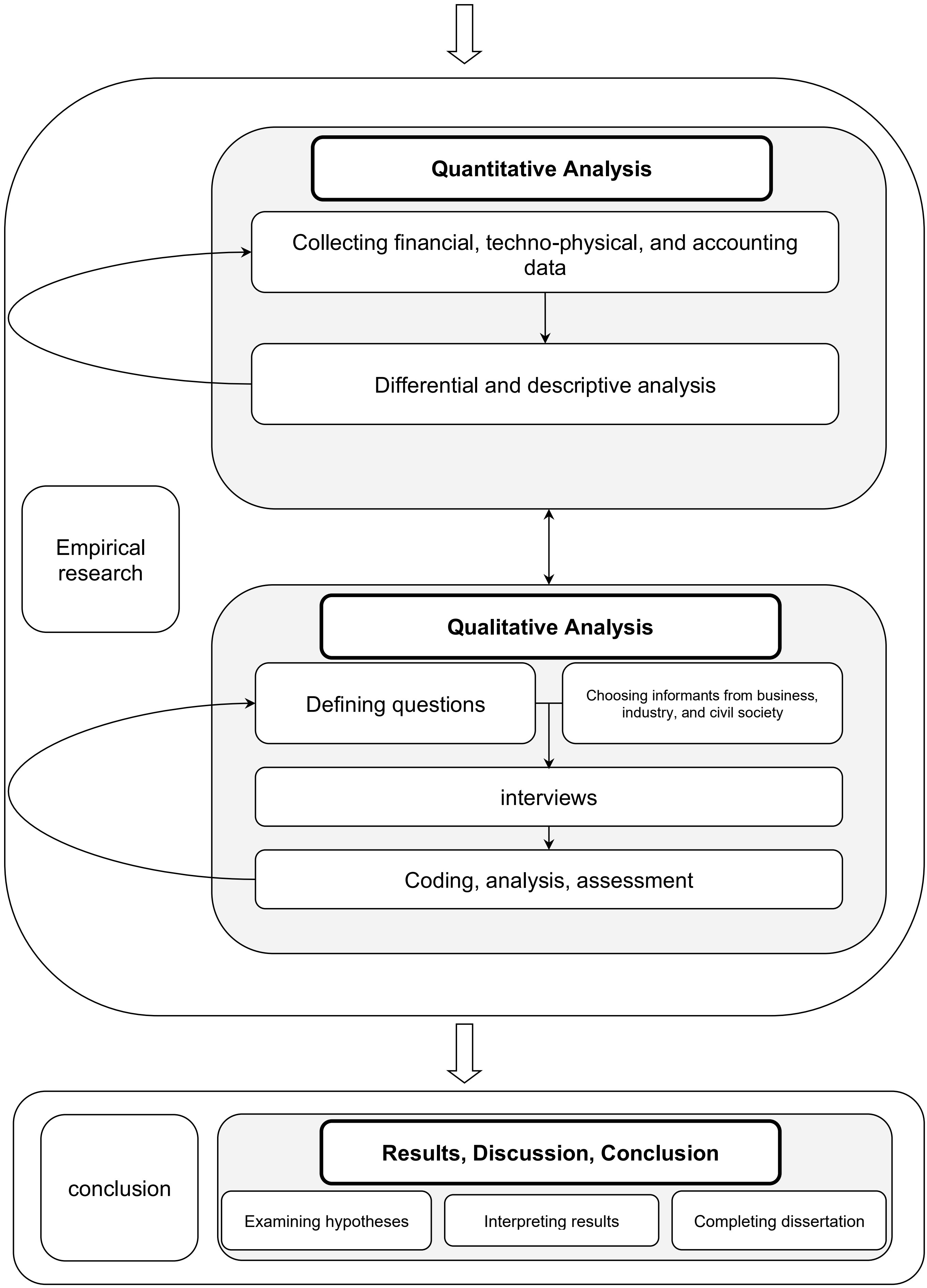
Regarding specific cases of transition these questions can be expressed as follows:

4. How do techno-physical changes in the electricity system influence the ownership structure, differential accumulation, and power relations in the sector?
5. How do those power shifts in turn influence the ways and means of transition?

3.4 Research outline

Figure 1: Research outline




Quantitative Analysis
Collecting financial, techno-physical, and accounting data
Differential and descriptive analysis
Empirical research
Qualitative Analysis
Defining questions
Choosing informants from business, industry, and civil society
interviews
Coding, analysis, assessment
conclusion
Results, Discussion, Conclusion
Examining hypotheses
Interpreting results
Completing dissertation

3.5 Conceptual Framework

In this section, I present my approach to the study of energy transition and power.

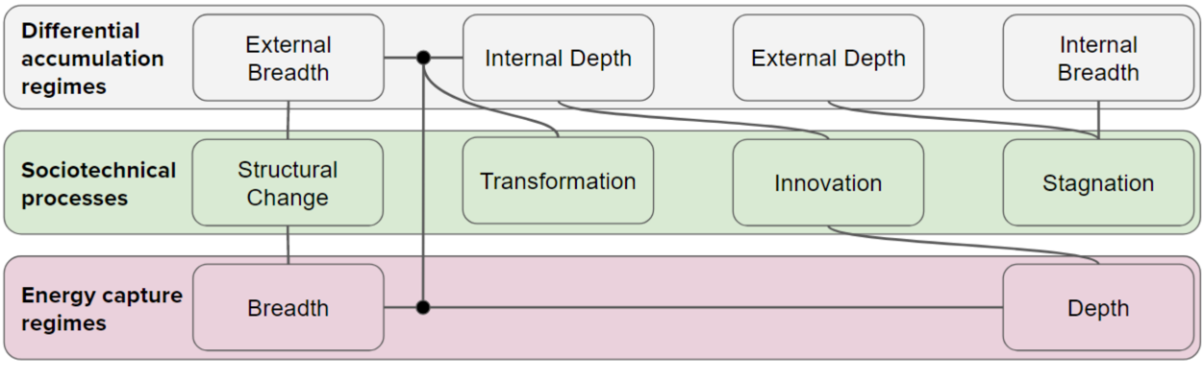
Energy regimes are deeply related to modes of power. The (re)production and (re)distribution of energy systems and their desired and undesired products are both a capitalized phenomenon and a precondition of capitalization. Therefore, the perspective accounts for the relations between business, industry, and energy capture as they define conditions of social power accumulation, its redistribution, and the course of socio-technical change. Power over energy can be asserted and contested both regarding the direction of changes in energy capture and regarding the capitalization of energy-related industries.

As discussed in the literature review section, spatio-physical conditions, socio-technical possibilities, and social power institutions co-determine the scope, pace and limits of both societal energy capture and social power accumulation (see Section 2.2.5 and 2.3).

Figure 2 represents the three interrelated components of the Business-Industry-Energy perspective on energy transitions - differential accumulation regimes, socio-technical processes, and energy capture regimes.

Energy capture regimes (see Figure 2, bottom tier) delimit the socio-technical conditions of energy extraction, conversion, and utilization. Rooted in the institutions of private ownership, investment, and capitalization, power accumulation in capitalism is contingent on the command and expansion of energy capture. Continuous accumulation and hierarchical expansion are historically coupled with growth in energy capture. The scope and limits of accumulation, both within a given sector and on a wider social scale, are thus partly set by biophysical factors, their given spatial distribution, and the finite character of planetary space itself (see Section 2.3).

Figure 2: The Business-Industry-Energy Perspective on Energy Transitions



Energy capture can expand (or contract) through *breadth*, *depth*, or a combination of the two (see Figure 2). By *breadth* I refer to primary energy consumption (measured in Joules). By *depth* I refer to net energy measures, and measures of conversion efficiency (expressed as a percentage). Thus, expansion in *breadth* would include intensification and diversification of primary energy extraction and consumption, like in the wider use of natural gas as energy source, enabled by the development of compressors and steel pipes (Smil, 2017). An increase in *depth* would entail higher EROI, or greater conversion efficiency, as in the rise in EROI for oil and gas production in the USA during the first half of the 20th century (Guilford et al., 2011), or the high efficiency of combined-cycle gas turbines in relation to other technologies (Smil, 2017). An example of increase in both *breadth* and *depth* is the transition to steam, which included both a leap in the breadth of coal consumption and in conversion efficiency of fossil-based prime movers (Smil, 2017).

Every social order depends on the natural environment and social production to sustain itself. Within hierarchical societies, however, it is not merely production, but its control, that defines the social order. Under capitalism, the institutions of private property, investment and capitalization channel reproductive and transitional processes (Bichler & Nitzan, 2023).

Differential accumulation regimes (Figure 2, upper tier) are related to the business-regulation nexus, the two primary intertwined organizational bodies of capital - corporations and government organs. Bichler & Nitzan (2009) identify four differential accumulation strategies associated with it: external breadth, internal depth, external depth, and internal breadth. These are strategies dominant capital can employ to achieve and increase differential accumulation (See Section 2.2.3).

Socio-technical processes (Figure 2, middle tier) are related to industry, they represent socio-technical development and are inherently connected to business-regulation strategies. I define four generalized types of socio-technical processes resulting from business-industry-regulation dynamics: *structural change*, *transformation*, *innovation*, and *stagnation*. *Innovation* and *stagnation* can be defined as path-reproducing processes, in that they deepen path-dependency, while *structural change* and *transformation* can be defined as path-altering processes.

Innovation is the reconfiguration and improvement of a certain socio-technical configuration. It does not transform, but rather enhances, an existing socio-technical path. Business engages in selection and promotion of specific technologies and upgrades, while simultaneously suppressing others. This process is related to internal depth strategies, like cost-cutting, and may increase the depth, i.e., efficiency, of energy capture. For example, the promotion and continued development of the internal combustion engine, over other possible motive power sources like the electric motor, in the early automobile industry can be seen as innovative (Hadjilambrinos, 2021).

Stagnation relates to processes of sectoral power concentration which block innovation, green-field development, and change. This process is related to internal breadth and external depth strategies, i.e., mergers and acquisitions, and stagflation, respectively. Dominant capital finds these paths to be more differentially rewarding, yet they reinforce path-dependency and inhibit development. For example, the current under-investment in research and development and "innovative insufficiency" of the oil sector (Matkovskaya et al., 2021: 5), which is dominated by a handful of "oil majors", can be seen as stagnation.

Structural change is a socio-technical process in which scale and breadth play a central role. It includes large-scale infrastructure developments, and the mutual reconfiguration of already-established technologies. This process is related to external breadth, i.e., green-field investment, and typically consolidates oligopolies which take advantage of economies-of-scale, as well as to rapidly rising breadth in energy consumption. For example, the interrelated industrialization, private-automobile proliferation, suburbanization, and massive transportation infrastructure development that characterised early 20th century urbanization could be seen as a process of socio-technical structural change (Mattioli et al., 2021).

Transformation is a process of deep, path-altering socio-technical change. It includes the introduction and expansion of new technologies, primary sources, and/or socio-technical conditions. It is associated with both rapidly increasing depth and breadth expansion in energy capture, namely, increased EROI, and primary resource consumption, respectively. It is related with a combination of internal depth and external breadth, i.e., cost-cutting and green-field development, respectively. This strategic combination is a diversion from the more prevalent cycle of internal breadth-external depth. For example, the transition to steam and the advent of extensive fossil-fuel consumption can be seen as transformative (Malm, 2016). In a sense, 18-19th century proletarization processes can also be understood as an energy-related socio-technical transformation, as they included an increase in both the breadth and depth of labour exploitation, combined with industrial innovation and green-field development (Thompson, 1963).

A distinction can be made between path-altering (or setting) transitions, which include changes in the depth and breadth of energy capture, thus changing the preconditions of accumulation and hierarchical growth, and path-reinforcing processes, which may result in the redistribution of power between social groups. Growth in capitalist societies is contingent on rising energy consumption, and so is the stability of continuous power accumulation processes. Thus, in a broad sense, power accumulation in capitalism is also contingent on concentration and control of energy capture and utilization. Nitzan and Bichler (2009) single out internal breadth and external depth as the two main strategies of differential accumulation. These strategic sabotage patterns shape and constrain the scope and pace of socio-technical change. I suggest that in the rare cases where socio-technical change includes a combined increase in energy capture breadth and depth (transformation), or a significant rise in breadth (structural change), external breadth and internal depth become viable paths for differential accumulation, giving rise to transformative socio-technical processes (see Figure 2).

Path-altering transitions would be those which change the basic configuration of power, energy capture and the institutions of capital. These include the examples I presented under the transformation and structural change categories. Path-reinforcing transitions would be those which affect dominant groups' ability to foresee and secure future conditions and alter power relations within the energy-related industrial sectors. An example of the latter is the introduction of alternating current for electricity transmission in the late 19th century that enabled the mergers of small direct-current-based stations and the consolidation of large-scale, centralized utilities (Hughes, 1983).

As Malm (2016) argues, the transition to steam brought about a new social order in which fantastic growth rates, based on increasing fossil-fuel consumption, could be sustained, labour could be more effectively controlled, and the institutions of private property, investment, and capitalization could be refined and developed. Thus, the scope of social power accumulation itself was simultaneously redefined, alongside the rise of new industrial elites. In contrast, Christophers (2022), DiMuzio (2012), and Newell (2021) have all demonstrated dominant capital's ability to restrict and appropriate contemporary transitional processes. This sustained ability indicates that changes were not significant enough to enable combined green-field-and-cost-cutting-based destabilization or threaten their dominance. Nevertheless, renewable-energy-based decarbonization may prove unique when examined from the perspective presented above. If carried out significantly, the process may imply a combined decrease in depth and breadth of energy capture, i.e., declining EROI and decreasing energy consumption due to fossil-fuel phase-out, respectively. Resulting in declining energy capture rates, this process would also alter the conditions of accumulation, yet in a power negating rather than power enhancing way.

The literature has acknowledged the need to understand the workings of power in energy transitions under capitalism (Feola, 2020). To do so, one must examine transition's dialectical relation to capitalization – how transition affects power accumulation, and how capitalization affects transition.

Furthermore, evaluating the relationship between energy capture and social form is crucial to the discussion of energy transition (Fix, 2021). The issue has hitherto been explored at a high level of abstraction, namely the general relation between hierarchical social form and energy capture. The proposed perspective develops this line of inquiry further by tracing relations between differential accumulation strategies and changes in potential societal energy capture. It enables us to explore the ways in which ownership structures, income distribution, energy capture, and strategic sabotage play out in the political economy of energy transitions.

3.6 Hypotheses

The research hypotheses are based on the literature review and the framework presented in the previous section. They can be divided into two groups: the first regards trends in historical business-industry-energy dynamics and associated socio-technical change processes; the second regards the analysis of contemporary renewable-energy-based decarbonisation transitions.

Group 1

Hypothesis 1

A combined expansion in the breadth and depth of energy capture is coupled with both internal depth and external breadth pathways and related to transformative socio-technical processes.

The first hypothesis stems directly from the conceptual framework developed for this study. It describes the expected energy capture and business strategy dynamics which accompany transformative socio-technical change.

Hypothesis 2

External depth and internal breadth strategies are related to periods of increased path-dependency.

The second hypothesis stems directly from the conceptual framework developed for this study. It describes the expected business strategies which accompany periods of entrenchment and socio-technical reproduction.

Group 2

Hypothesis 3

Decentralisation and renewable-energy-based decarbonization of electricity generation adversely affects the profits (lower profits), risk perceptions (higher risk), and capitalization (lower market capitalization) of dominant generation firms.

The third hypothesis relates to the expected initial effects of significant renewable and decentralized penetration on dominant generation firms. In addition to divestment and unbundling, the penetration of decentralised generation induces a decrease in output share for conventional generation firms, the increasing competitiveness of decentralised prices which drives spot market prices down, and greater uncertainty regarding expected return on equity and future streams of income.

Hypothesis 4

Adverse effects of decentralisation on conventional generation firms are compensated for through regulatory mechanisms, and the centralization of ownership over the diminishing conventional capacity which enables dominant producers to increase differential prices and profits.

Hypothesis 4 relates to the paths dominant firms may adopt to regain sectoral control. It suggests that dominant firms will rely on the dependence of systems with high renewable penetration rates and insufficient storage on conventional reserve capacity to achieve differential gains.

Hypothesis 5

Dominant generation firms regain sectoral control by their threat to reliable supply.

Hypothesis 5 is directly related to Hypothesis 4. It suggests that when faced with decreasing output share and increasing uncertainty dominant firms may build on systemic dependence on conventional capacity to increase and secure differential accumulation. This hypothesis is based on the analytical framework, which suggests that a decline in energy capture breadth and depth is related to increased reliance on to internal breadth and external depth business strategies, i.e., mergers and acquisitions, and stagflation, respectively, and a retardation of socio-technical change processes. It is also based on the concept of strategic sabotage presented in Sections 2.1.2.1 and 2.2.4 of the literature review, and on the reliance on conventional capacity in the context of high-RES penetration anticipated in Section 3.7.2.2.

3.7 Case studies

I explored two complementing case studies: 1. Energy transitions in the UK, focusing on the culmination of the transition to steam and industrial capitalism during the turn of the 20th century and its aftermath. This represents a completed socio-technical transformation and ensuing long-term dynamics of socio-technical change and stagnation; and 2. The *Energiewende* – the energy transition currently in progress in Germany that combines a techno-physical transformation of the German electricity system with a reorganisation of the sector's ownership structure. This represents a contemporary decarbonization process. To achieve a better understanding of such unfolding and undetermined, yet arguably crucial, socio-technical processes, the *Energiewende* is studied against the fulfilled transformative process of the transition to steam in the context of their respective energy capture and differential accumulation conditions.

The UK was chosen since it is considered to have led the transition to steam, and the related fossil fuel breakthrough (Nuvolari et al., 2011). This early transition and the relatively abundant techno-physical and economic data make it a suitable case study through which to examine the relations depicted in the conceptual framework, and different instances of socio-technical change.

The *Energiewende* in the German electricity sector is a suitable contemporary case study for several reasons: it is a relatively advanced case of electricity system decarbonization originating in the 1990's; it includes significant VER and DER penetration, alongside conventional capacity decommissioning; and it combines both a state-led national energy transition initiative, high energy sector involvement in policy-making processes, and significant grassroots, citizen-led energy democracy and sustainability struggles.

3.7.1 The energy transition to fossil fuels in Britain

The British case study is different from the German one in two distinct ways: in the first place, rather than analysing a contemporary, undetermined process of sociotechnical change, I focus on an historical, completed, energy transition - the transition to steam in British industry and its aftermath during the 19th century and the turn of the 20th century; secondly, I attempt to outline the broad relations between changes in energy capture and differential accumulation regimes throughout the 20th century. Working on three main assumptions, I study the second half of the 19th century and the years leading up to WWI in Britain in detail to trace the consolidation of dominant capital's Modern rule, and the corresponding processes in the field of societal energy capture. I study 20th century processes in broad strokes to identify questions and issues for future research.

The three main assumptions are as follows: 1. That the turn of the 20th century was the period in which the cyclic movement between breadth and depth regimes of differential accumulation which characterises the 20th century was initiated (Nitzan & Bichler, 2009); 2. That, propelled by the maturation of industrial capitalism and the institution of waged labour,[54] this period witnessed the consolidation of a novel form of business power and control;[55] 3. and that during the late 19th century and the years leading up to WWI the wide societal energy transition to fossil fuels (set in motion a century earlier) was broadly fulfilled, and ”the fundamental means to realize nearly all of the 20th-century accomplishments were put in place” (Smil, 2005: 5).

It is impossible to draw the line and point to a decisive moment when the capitalist mode of power replaced its feudal predecessor, when citizens of the autonomous city-state, the bourg, came to replace the landed aristocracy, the captains of industry came to replace nobility, and differential profit came to replace rent. Yet it could be broadly stated that while the 18th century in Europe and Britain still witnessed the clash between the declining old regime and the rising capitalist order, by the mid-19th century Europe and Britain in particular had entered what Eric Hobsbawm (1977:43) termed *the age of capital* “when the world became capitalist and a significant minority of ‘developed’ countries became industrial economies”. By this time, the British state itself, and its capacity to wage war and exert taxes, had become a fully capitalized entity (Di Muzio & Dow, 2017).

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[54] Proletarization and the institution of waged labour, as well as being an energy transition in the breadth and depth of the control of human labour power, were a crucial development in the consolidation of the capitalist mode of power as they enabled a new form of direct control of the population, and the subsequent capitalization of the degree of this control. By 1871, industrialization over half of the working population were employed in factories (and considerably more than one half of output was produced in factories),

[55] This form of business control is based on the corporation as a central organizational structure, the institution of *absentee ownership*, the spread of differential capitalization as a quantifiable measure of power, and the rise of large and dominating business formations rooted in the aforementioned developments (Nitzan & Bichler, 2009; Hannah, 1983; Veblen, 1924).

During the 19th century the practice of the quantification of social power using differential pecuniary measures was yet to be fully established, and differential profit was yet to be instituted as the ultimate measure of quantified power. Nevertheless other, cruder, differential quantified measures of power could have been applied by capitalists. The study of this period is also the study of the maturation of the logic of differential capitalization.

Arrighi (1994: 213) understands the process of industrialization of Britain during the 18th and 19th centuries as part of the "third and concluding moment of a historical process that had begun centuries earlier". According to him, this long historical process included three distinct periods of rapid industrial expansion in England, accompanied by the "financial expansion in the capitalist world-economy at large", the first based in Florence, the second in Genoa and the third led by Amsterdam (Arrighi, 1994: 214). The industrialization of Britain during the 18th and 19th centuries was centred on the English textile and metal industries which also led the way in the diffusion of steam power (Kanefsky, 1979).

3.7.1.1 The diffusion of steam power in British industry

While coal had been used as a source of thermal energy for millennia, its combustion in combination with a new prime mover, the steam engine, "as a source of mechanical – rotative – energy" in manufacturing and transportation constituted a qualitative shift (Malm, 2016: 11). Britain clearly led the global transition to fossil fuels during the 18th, 19th, and early 20th centuries.

Nevertheless, while it retained a dominant position as producer and consumer of fossil fuels, its share declined during the second half of the 19th century, as industrialization and the transition to fossil-fuelled steam power spread globally. According to a calculation based on Gilfillan & Marland's (2021) *Global, Regional, and National Fossil-Fuel CO2 Emissions*

(1751 - 2014) dataset, Britain accounted for averagely 95% of global annual C02 emissions from fossil fuel consumption between 1751 - 1820, 72% between 1820 - 1850, and still accounted for averagely 50% of global annual C02 emission between 1850 - 1870. Between 1870 - 1900 Britain's average share of annual global C02 emissions from fossil fuel consumption dropped to 32%, still accounting for almost a third of global C02 emission from fossil fuels.

The diffusion of steam power in British industry was itself differential. Kitsikopoulos (2023) argues that the three main sectors in which steam power diffusion occurred between 1741-1800 were mining, textiles, and iron manufacturing (in terms of absolute aggregate steam power capacity). However, in terms of the relative share of steam power in total sectoral energy output, Kitsikopoulos (2023: 13) stresses that the early diffusion of steam power in mining was overwhelming, and "steam power came to nearly monopolizing pumping operations in the pre-Watt era and continued to do so thereafter". Regarding textiles, the sector which came second in terms of absolute aggregate steam power capacities, Kitsikopoulos estimates that by 1800 one-fifth of energy use in textiles was steam-powered, while the rest was water-powered. Finally, in the case of iron manufacturing, data limitations inhibit a precise estimation of the relative contribution of steam in sectoral energy output, yet Kitsikopoulos suggests that by 1800, 87% of blast furnaces in Britain were steam powered (Kitsikopoulos, 2023: 16).

Regarding the diffusion of steam power during the period of 1800-1870 and its gradual domination of British industry, Kitsikopoulos calculates an average annual growth rate of 47% in industrial steam power capacity (compared to a mere 2.5% average annual growth rate in waterpower and 0.5% average annual growth rate in wind power), while noting that it did not follow a linear growth trajectory (Kitsikopoulos, 2023: 234-236). The three most energy intensive sectors in absolute terms of total energy output and steam-powered energy use remained textiles, mining, and metal manufacturing (in this order of absolute energy output). Yet in relative terms of steam power diffusion in 1870, metal manufacturing came first, steam accounting for 98% of total installed horsepower (hp), textiles second, steam accounting for approximately 96% of total installed hp (97% in cotton), and mines came third, steam accounting for 94% of total installed hp (Kitsikopoulos, 2023: 236). In Kanefsky's (1979: 349) words: "Rapid expansion of the coal, iron and urban textile trades, and to a lesser extent copper and lead production, all depended on the availability and versatility of steam power… By I870 the transformation [from water to steam power, T.L.] was virtually complete".

3.7.1.2 "British economic growth" debates

Considering the centrality of the idea of the industrial revolution (under any of its many names)[56] and its British roots in Western historical imagination (Barca, 2011), it is surprising how limited are the historical national accounts and physical data available to us concerning the period of the mid-18th - turn of the 20th century in Britain. For physical data there is still a heavy reliance on Kanefsky's (1979) unrivalled PhD dissertation of the diffusion of steam power in British industry.[57]

In the field of economic growth accounting, the empirical evidence is also meagre. In contrast to the USA, British authorities did not hold manufacturing censuses during the 19th century (Hannah & Bennet, 2021), as a result, economic and business historians rely on an assortment of alternative sources "all of which have inconsistencies of coverage over time and generally cover only a few sectors" (Lieshout et al, 2021: 130).

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[56] The idea of a singular, confined, historical moment of industrial *revolution* was challenged by concepts such as the *industrious* revolution (De Vires, 1994), and the dismissal of its "revolutionary" characterization (Hartwell, 1990), among other critiques.
[57] For a lethal critique of Warde's estimates and a respectful critical engagement with Novulari's, see Kitsikopoulos (2023: 15, 149).

Regarding population censuses, Higgs et al. (2013: 6) declare that “before the nineteenth century, the British state does not seem to have been very interested in general population statistics” and while population censuses were performed during the first half of the 19th century, this became a systematic endeavour only after 1851.

As Francis (2022) points out, historical national accounts estimations suffer a high degree of uncertainty, a degree ever rising, the farther back we go in time and the farther away from the countries, such as the UK and USA, for which historical data is relatively abundant. After considering the uncertainty of relative UK/USA GDP estimates according to different estimation processes, he concludes that these are in fact “known unknowns”. Nevertheless, there is a wide literature on the economic history of Britain between the late 18th century and the early 20th century (spanning what is sometimes termed the First and Second industrial revolutions), ongoing efforts to produce and refine estimates of British historical national accounts, and a long-standing debate on the nature of British economic growth throughout the long 19th century.

The pioneers of historical British national accounting estimation were Phyllis Deane and Max Cole, who used novel proxy measures and modelling techniques to produce, in 1962, the first set of estimated historical national accounting time-series for Britain (Broadberry et al., 2015). Drawing on this and other works such as Lewis (1967) yet significantly revising, refining, extending and renewing them, Charles H. Feinstein (1972) published his series of British national accounts estimates (1855 - 1865) for which he continued to publish revisions until his death in 2004, and which, to date, continue to be a predominant source for British economic history analysis (Solomou & Thomas, 2022). Feinstein had no pretence to venture deeper into the past with his estimations, though Solomou and Thomas (2022) have recently published a revised series of income-side GDP estimates for 1841 - 1920 based on Feinstein's own latter improvements as well as additional research.

During the 1980's the early rates of growth ascribed to the British economy between 1700-1830, resulting from Deane and Cole's estimations, were challenged by researchers such as Crafts and Harley (1992; Crafts, 1983), who suggested that rates of growth were significantly slower than previously estimated and that until the third decade of the 19th century total growth in real output of commodities lay under 2%.

Malm (2016: 32) points out that a sectoral analysis of the rates of growth in output for this period, based on the same estimations used by Crafts (1983), reveals a differential growth pattern: while the *aggregate* growth rate of output lay steadily under 2%, the annual growth rate of output in the cotton industry doubled between the 1770's and 1780's, reaching an average annual growth rate of 12.76% and coinciding with the monopolization and differential industrial developments in this sector. These differential insights were already raised during the 1980s by such researchers as Mokyr, Pollard, and McCloskey (Mokyr, 1987: 314-315) who pointed to the blind spots of aggregate growth analysis in which rapid growth rates in certain sectors might be "diluted".

A related debate regards the development of real wages, their share of GDP, and the implication of these for earnings inequality. Williamson argued that income distribution between the late 18th century and the turn of the 20th century followed a bell-shaped Kuznets curve, in which earning inequality soared up until the mid-19th century, and subsequently declined, following an "egalitarian levelling" which reverted income inequality over the second half of the 19th century (Feinstein, 1988b: 706-707). Feinstein, on the other hand, suggests that levels of earnings inequality were relatively stable throughout the 19th century. Feinstein (1998: 649) further argues that real wages and the working-class standard of living stagnated between the late 18th and mid-19th centuries "despite the fact that in many parts of the country they were starting from a very low level". He argues that a turning point appeared in the mid-19th century but that it was "only after the post-1873 downturn in prices that average real earnings finally accelerated".

A similar argument is made by Allen (2007) who, relying on Feinstein, Crafts and Harleay's estimations, argued against Clark who claimed that the average unskilled worker's real income rose faster than real output per capita between the late 18th and mid-19th centuries. Allen (2007: 2) argues to the contrary that the first half of the 19th century was characterized by stagnant real wages despite rising rates of output per capita. He further argues that during this period "the share of profits in national income expanded at the expense of labour and land", and that real wages began to grow only during the second half of the 19th century, while the rate of profit stabilized.

Similar debates arose regarding output growth in Britain during the second half of the 19th century. A common argument has been that a retardation of growth occurred between 1873 - 1913, known as the *British climacteric*, yet this view has been later contested, and there are disagreements over the initiation, duration, and severity of the decline (Crafts et al., 1989; Feinstein et al., 1982; Lewis, 1967). Significantly, Feinstein et al. (1982) argue that the manufacturing sector had a small role in the overall decline in output between 1873 -1913. To the contrary, they claim that the growth rate of Total Factor Productivity (TFP) in British manufacturing between 1873 - 1899 was "no lower" than it was between 1856-1873, thus, it moved in the opposite direction to the general TFP. Yet in comparison to earlier periods, the decline in manufacturing TFP between 1899 - 1913 was the most significant.

It is now the common view that the so-called *long depression* in Britain, was a crisis of business profits, rather than of production (Capie & Wood, 2013). While prices tended to fall, causing great consternation amongst British industrialists, and prompting much debate on the matter, there is little or no empirical evidence of a significant decline in British production, save for in the agricultural sector (Capie & Wood, 2013; Musson, 1959).

3.7.1.3 The rise of large firms and corporations in British industry

Another phenomenon which accompanied the energy transition to fossil fuels was the appearance of large industrial business formations, and, starting in the mid-19th century, the corporatization of British manufacturing. Following the diffusion of steam power, large firms first proliferated in the cotton industry which, during the turn of the 19th century, rapidly evolved from a sector characterised by small-scale family-based production units to a sector characterised by large-scale capital-intensive enterprises, each controlling hundreds of workers (Hannah, 1983).

While the size of firms, based on the scale of employment, may have been conceived of differentially by the rising industrial capitalists, Hannah (1983) and Payne (1967) argue that increasing firm size did not lead to significant concentration of production in the first half of the 19th century, seeing as market expansion and population growth were equally rapid. Bennet, et al. (2020) argue that, omitting the smallest size categories of under five employees, firm size distribution in Britain remained fairly constant between the late 19th century and today (Hannah & Bennett, 2021) (see Table 2).

Table 2: Percentage of firms by size category, Britain, 1851–81 and 2017, for firms with five employees and upwards

Employees	1851	1861	1871	1881	2017
5-9	55.0	54.0	51.1	50.7	50.2
10-19	27.9	28.3	29.0	27.4	27.1
20-49	12.6	12.5	13.6	14.2	14.5
50-99	2.5	2.7	3.1	3.8	4.5
100-199	1.1	1.3	1.7	2.0	1.8
200-249	0.2	0.3	0.4	0.5	0.5
250-499	0.5	0.6	0.7	0.8	0.8
500+	0.2	0.3	0.4	0.8	0.7

Reproduced from: Bennett et al., 2020b: 115, Table 5.2.

They further point out that while most firms (over 60%) in all sectors were small-scale firms, engaging under five employees, "nearly all" firms employing over 500 were "textile manufacturers or steel and coal owners who could be employing several thousand people" (Bennet, et al., 2020: 113-114).[58]

Thus, while throughout the first half and mid-19th century it seemed that expanding markets maintained conditions of high, and in some sectors cutthroat competition, Hannah (1983: 13) argues that "these very conditions… contained within them the impetus to the division of labour which in the long run was to result in the greater concentration of output in the hands of large firms", and increasing business centralization in the late 19th century.

[58] The few exceptions were found in the brewery sector, which tended early to amalgamation and largeness, the rising chemicals and paper, printing, and publishing sectors, and a handful of firms which succeeded in monopolizing a specific industrial process or development, or a specified product niche, such as in the tobacco industry, and other consumer products (Hannah, 1983; Hannah & Bennett, 2021; Payne, 1965).

Institutional and legislative developments that ripened in the mid-19th century in Britain also shaped the changing business landscape, as they themselves were shaped by new business needs and interests. Between 1844 and 1852 the legislative framework which was to establish joint stock companies and limited liability companies as dominant business forms within the industrial sectors was put forth. The rise of the corporate form was neither quick nor sudden (Cheffins, 2008; Payne, 1965).[59] Significantly, by 1885 the sectors in which the limited liability form was most influential were shipping, iron, coal and steel, and cotton. The diffusion pace of the limited liability form then increased during the 1890's from 2,515 accompanied by intensifying amalgamation processes, predominantly in the textile, brewing, iron, coal and steel, cement, and paper industries (Payne, 1965; Shannon, 1933).

Hannah (1983: 20) points out that corporatization, and the larger use of credit, were in themselves processes which drove centralization and firm size growth through amalgamation. He explains that early merger activities were pursued as a solution to the financing limitations of smaller companies, and as a means to accessing "economies of scale in the capital market".

More generally, Hannah (1974: 2) argues that the turn of the 20th century (1880 - 1918) "marks the beginning of merger activity of the modern type" in the British manufacturing industries, meaning "a systematic tendency to large-scale enterprises, created by sustained merger activity as opposed to occasional acquisitions and extended partnerships". Hannah (1983: 21) describes a convergence of "technical, commercial and also financial" conditions during the late 19th century which resulted in a new intensity and scale of merger waves in this period. He argues that "This movement towards industrial concentration was historically unprecedented and it

[59] The Joint Stock Company was not a novel institutional form, yet prior to the mid-19th century, its use was limited to commercial firms. As the source of profits shifted from the control of commerce to the control of a rapidly developing industrial terrain, the organizational structures of business needed to be rearranged.

created manufacturing enterprises with capitals distinctly larger than the early nineteenth-century cotton lords could have aspired to (Hannah, 1983: 22).

There was a long-standing accusation of British captains of industry by business historians for their reluctance to hand over managerial control and thus "severely limiting manufacturing scale and scope, relative to the US and Germany" (Foreman-Peck & Hannah, 2024; Hannah & Bennett, 2021: 2; Payne, 1965). Yet the turn of the 20th saw increasing corporatization rates in British commercial and industrial firms which enlisted on the LSE (Cheffins, 2008).

With a coinciding maturation of an industrial shift to steam power, the rise of dominant capital in the form of large-scale, centralized corporations, and the initiation of differential internal breadth - external depth cycles of differential accumulation, the turn of the 20th century in Britain is an intriguing case study for the analysis of business-industry-energy relations in periods of significant socio-technical changes.

3.7.2 The German *Energiewende*

In this section, I introduce the German case study. The first part lays out a brief description of the *Energiewende*'s major features. The second discusses the main industry-side changes in the power sector and their significance.

3.7.2.1 The German *Energiewende* and the electricity sector

The transition of the German electricity sector, as part of the German *Energiewende*, reflects changes in both socio-technical conditions and organised power. As "one of the world's most ambitious and comprehensive national energy transition initiatives" the Federal Government's Energy Concept sets environmental, economic and social goals to be achieved through the decarbonisation of the energy system (Quitzow et al., 2016:163).

Energiewende legislation and policies award a central role to transition in the electricity system (Haas & Sander, 2016). This transition combines increasing the share of RES in electricity consumption to 80% by 2050 while simultaneously phasing-out nuclear and coal-based power plants by 2023 and 2038, respectively (AtG§7, 1959; EEG ,2000; KVBG, 2020). These goals are supported by a diverse policy-mix, of which the Renewable Energy Sources Act (EEG, 2000) is the most prominent.[60] The decarbonisation process in the German electricity sector, and the simultaneous nuclear phase-out, are shaped by decades-long social struggles, and enjoy high public support (Leiren & Reimer, 2018).

The early roots of the *Energiewende* lie in 1970's and 1980's German ecological and anti-nuclear social movements. The 1986 Chernobyl disaster strengthened advocacy for an alternative to the nuclear and fossil-based energy regime, and early institutional movements in this direction included the passing of the first feed-in-tariff (FinT) for renewables (Stromeinspeisegesetz) in 1990 (Haas & Sander, 2016) and the decommission of two nuclear power plants located in the former GDR for safety reasons.

The first major structural changes in the electricity sector occurred in 1998 with the liberalisation of the sector, in accordance with the European Union's 96/92/EG directive (Müller et al., 2008). Germany's power sector preceding liberalisation was dominated by privately-owned vertically integrated regulated monopolies. Liberalisation implied the "unbundling" of the sector: its separation into segments and the creation of wholesale electricity markets (Joskow, 2006). In the wake of this restructuring, the 'big 4' electric utilities, namely, RWE, E.ON, EnBW, and Vattenfall, consolidated their power in both the German and

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[60] The Renewable Energy Sources Act (EEG, 2000) first set a fixed, above-market, Feed-in-Tariff for renewables, and mandated their connection to the grid by the Transmission System Operators. This legislation laid the foundation for the rapid RES penetration in the German electricity grid during the first two decades of the 21st century.

European markets, while retaining full overview of the market through their control of three of the four German transmission system operator firms (Kungl & Geels, 2018).

In 2000 the Renewable Energy Act (Erneuerbare Energien Gesetz) was passed. Early Renewable Energy Act legislation (EEG 2000) set fixed, above-market feed-in-tariff price levels for renewable energy, and mandated grid priority to renewables. This regulatory framework threatened to destabilise dominant conventional firms who were all at once losing output share, gaining differentially lower returns per unit of electricity, facing increased competition, and failing to invest in renewables, investing instead in new conventional capacity and costly take-overs (Kungl & Geels, 2018).

Though nuclear phase-out and RES penetration date back to the early 1990's, it was the 2000 EEG legislation which kick-started rapid renewable energy sources penetration, guaranteeing above market price feed-in-tariffs for a period of 20 years to renewable generation, and establishing mandatory grid priority for RES (Rogge & Johnstone, 2017). Consequently, the share of RES in total net nominal capacity has risen steadily since 2000, while the share of conventional energy resources has declined. Since 2017 RES account for over 50% of total net nominal capacity and in 2021 RES supplied 40% of total net generation. Several features of the *Energiewende* have initially supported strong citizen involvement in RES penetration. Indeed, the early trend shows high prosumer shares in new installed RES capacity, decentralisation and a growth in citizen-energy projects, though these have been in decline in recent years (Kahla et al., 2017). Moreover, dominant firms were late to invest in RES generation, and it seemed as though their control of the sector was gravely destabilised (Kungl & Geels, 2018).

While the transition away from nuclear power was imposed upon them, dominant utilities used their power in negotiating the 'Atomkonsensus' of 2000, an agreement between the government and electric utilities on the future of nuclear power in Germany. This agreement formed the basis of the 2002 amendment to the Nuclear Energy Act (Atomgesetz AtG) which delineates the nuclear phase-out.

Dominant conventional utilities continued to contest phase-out policies and lobby against them. In 2009 their efforts bore fruit and the CDU-led[61] government halted the phase-out, extending the lifetime of nuclear power plants, despite strong public disapproval. Yet following the Fukushima disaster in 2011, the very same government overturned this decision, and the full decommission of nuclear capacity in Germany was completed in 2022. The coal exit, under the coal phase-out act (KVBG, 2021), administers gradually the full decommission of coal capacity by 2038. This enforced decommission of (still profitable) nuclear and coal installations have significantly influenced the development of techno-physical change (Rogge & Johnstone, 2017).

Dominant conventional utilities had also failed in their attempt to push for the construction of a capacity market in the 2016 German electricity market reform. This reform was instigated in response to increasing variable energy resource penetration and security of supply concerns. Instead of a capacity market mechanism, which would have secured broad and significant capacity payments for conventional generators, policy makers opted for strengthening the energy-only market and constructing a limited strategic reserve, with fixed capacity payments (Gawel et al., 2022). [62]

[61] CDU is the acronym of the Christian Democratic Union of Germany, a German conservative political party.

[62] This means that rather than establishing a separate capacity market, where conventional electricity generation firms could receive payment for conventional installed capacity as such, the German government decided to keep functioning with a wholesale electricity market only. In addition, it constructed a limited capacity reserve, enabling authorities to instruct generation firms to keep flexible capacities available as part of this capacity reserve under fixed and regulated prices.

In addition, strong business and institutional forces, both at the German and the EU level, have been pushing back against the fixed feed in tariff for renewable generators in favour of a "competition-oriented" approach. Building on public discontent regarding rising EEG costs and household electricity prices, and to save conventional electricity generation firms from insolvency, a set of amendments to the EEG law were drawn in 2014, 2017 and 2023. These amendments have shifted renewable energy policy from direct public subsidy to market-based mechanisms such as an auctioning system for new renewable capacity and compulsory direct marketing (Leiren & Reimer, 2018).

This shift is of great significance. While early Feed-in-Tariff measures have proven instrumental in instigating renewable energy sources penetration and decentralisation, market-led mechanisms clearly benefit big actors, changing the trajectory of transition (Morris, 2019).

From the start, the *Energiewende* has been a conflictual process. Though Germany is unique in its relatively broad consensus over nuclear phase-out and renewable capacity build-up, exactly how the *Energiewende*'s climate policy should be implemented has been continually contested by citizens, professionals, activists, policymakers, and industry (Beveridge & Kern, 2013). The rate and pace of renewable energy sources penetration, as well as nuclear and fossil-fuel phase-out, have been continually challenged from different directions. Struggles transpired over issues of energy-democracy and participation, policy instruments, local opposition to infrastructure development, government subsidy, electricity prices, and more (Paul, 2018; Reuswigg et al., 2016). A major policy-related development occurred in 2017 with the shift from Feed-in-Tariff to auctioning, as part of the general move from subsidy to direct marketing of RES and toward RES liberalisation. Even with built-in citizen-energy support mechanisms,[63]

[63] This refers to the 2017 amendment of the EEG§36g "Special auctioning rules for citizens' energy companies", as well as to the entitlement of small installation operators to a feed-in-tariff (up to 100 kW).

the move strongly benefited large firms at the expense of smaller actors, cooperatives, and prosumers (Leiren & Reimer, 2018).

To conclude, the Energiewende is a relatively developed case of transition in the electricity sector, which includes significant RES penetration, conventional capacity decommissioning, generation decentralisation, destabilisation of established business models, citizen-led energy democracy struggles, and contested policy measures connected to an entrenched neoliberal mindset. As such, I find it highly suitable for the study of organised power in energy transition.

3.7.2.2 Variable energy resource penetration - understanding industry-side changes in the Energiewende

The Energiewende brought major industrial, spatio-physical changes to the electricity system. These include Variable Energy Resources (VER) and decentralised energy resources penetration, nuclear and fossil-fuel decommissioning, and their techno-social effects.

VER are typically also Renewable technologies. Power generation from VER is dependent on environmental conditions and their output varies over time (Ambec & Crampes, 2019). Decentralised energy resources are less consistently defined. They include a diverse array of resources which can generally be characterised as being located in proximity to customers (on-site) and providing both electric power services and grid stabilisation services such as demand reduction, supply additions and ancillary services (Kahrl et al., 2021).[64]

[64] Ancillary services are active and reactive power, frequency, and voltage control services which help in maintaining grid stability.

The degree of VER integration is often referred to as ‘penetration’, denoting their share (%) in a system’s energy mix. Variability,[65] uncertainty, and non-synchronous generation[66] are all characteristics of VER which adversely affect grid reliability and stability (Abido et al., 2020; Impram, et al., 2020). Grid reliability is affected by the growing share of non-dispatchable resources[67] which complicates the ability of system operators to react to fluctuations in demand, particularly during peak load,[68] and to ensure universal and reliable supply of power on-demand. In addition, grid operation requires an ongoing balancing of load and available generation capacity over different timescales (D’costa et al., 2017). The displacement of dispatchable base load generators reduces system inertia, which complicates the maintenance of grid stability and may raise the potential for rolling black-outs, cascading failures, and damage to generators (Johnson et al., 2020).

Note that, as VER penetration increases, electricity systems rely increasingly on limited conventional capacity (in times of low variable generation) to sustain grid reliability. In the case of the *Energiewende*, not only does VER penetration increase, but conventional installed capacity is reduced through decommission.[69] This implies that, ceteris paribus, reliable electricity supply during peak load is dependent on a decreasing conventional installed capacity. Or in other words, in the context of increased grid instability due to high-RES penetration, reliable electricity supply during periods of high demand depends on smaller reserves of flexible backup capacities.

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[65] Intermittency and dependence on external conditions means that capacity varies over time and does not always meet nameplate capacity.

[66] Non-synchronous generators reduce the amount of rotational inertia available in a system. Grid stability decreases as a consequence (Johnson et al., 2020).

[67] I.e. resources which cannot be controlled by system operators and cannot be dispatched on command.

[68] The highest electric power demand on a grid over a specified period of time.

[69] Installed Capacity refers to the maximum sustained capacity at which a power-generating installation can run at.

3.7.2.3 Variable energy resource penetration and the “Big Four” German electricity firms

Preceding the liberalisation of the German electricity market, the ‘big-4’ dominant firms (RWE, E.ON, Vattenfall, EnBW) consolidated their control over the sector and increased their market share in generation (90% of Total Net Generation in 2004) (Kungl & Geels, 2018).

But as variable energy resources (VER) and decentralised energy resources penetration developed, dominant firms lagged behind in renewables generation, while instructed by the authorities to divest from certain assets and decommission nuclear and coal installed capacity. These firms began losing output share, profitability and influence (Kungl, 2015). Concurrently, a process of specialisation began taking place, with RWE and E.ON effectively splitting up the market between them, specialising in generation and supply, respectively (Berlo & Wagner, 2020).

Nevertheless, the dominant/non-dominant division is still significant to understanding power relations, especially with regards to conventional electricity generation. As can be seen in Table 3 (remade from BnetzA Monitoring Report 2022), the share of the five dominant firms in conventional Total Net Generation, though lower than during the first decade of the 21st century, is still significantly high (67% in 2021). Table 4 shows that dominant 5 firms’ share in conventional Total Net Nominal Generation Capacity remains over 50% in 2021, even following significant nuclear capacity decommission, which was solely held by dominant firms.

Table 3: Conventional Total Net Electricity Generation by the five largest German electricity producers 2020-21

Germany 2020			***Germany 2021***		
Companies	***TWh***	***Share***	***Companies***	***TWh***	***Share***
Dominant 5	175.0	65.3%	Dominant 5	198.0	67.0%
Rest	92.8	34.7%	Rest	97.5	33.0%
Total	267.8	100%	Total	295.5	100%

Source: BnetzA, 2022: 50.

Table 4: Conventional Installed capacity of the five largest German electricity producers 2020-2021

Germany 2020			***Germany 2021***		
Companies	***GW***	***Share***	***Companies***	***GW***	***Share***
Dominant 5	52.6	56.7%	Dominant 5	46.0	53.0%
Rest	40.4	43.3%	Rest	40.9	47.0%
Total	92.6	100%	Total	86.9	100%

Source: BnetzA, 2022: 52.

Thus, it can be said that conventional electricity generation in Germany is still dominated by five big firms.

3.8 Research population

The study explores relations of capitalist power, energy regimes, and transitional dynamics. Hence, to trace social power accumulation processes, I concentrate on the differential analysis of the performance of a certain business-governance group in relation to a wider group or benchmark in both case studies. In addition, to understand transitional processes and delineate energy regimes, I focus on pivotal processes of change in energy systems and energy capture regimes.

For the British case study, I concentrated on what I term *Energy-core* businesses in relation to the textiles industries, and a wide measure of mining and manufacturing industries. The Energy-core is the consolidating dominant capital group which consists of the era's most energy intensive industries, i.e., ferrous metals manufacturing, and engineering commodities, as well as the mining and quarrying sector, which provided for their main primary energy resource input. The differentiation between energy-core industries and other industrial sectors lies at the heart of the analysis of the relation between the energy transition to fossil fuels and the initial formation of dominant capital groups.

The main *energy-core* manufacturing sectors are ferrous metals manufacturing, which includes the initial manufacturing of pig iron from iron ore,[70] and its later use in the manufacturing of iron alloys such as steel and wrought iron, and engineering commodities manufacturing. Engineering commodities manufacturing includes the ferrous-metals-based production of engines, motors, tools, and equipment, as well as other engineering-related services.

During the 19th century ferrous metals manufacturing was revolutionized by the introduction of coal, and later coke as fuels, and developments in furnace techniques. These enabled a shift to high-volume and relatively inexpensive iron and steel production (Brikett, 1922; Smil, 2005). The ferrous metals manufacturing industry not only required great amounts of energy in mining, smelting, and forging, it also supported the flourishing of numerous other energy

[70] Pig iron, or crude iron, is the most basic manufactured intermediate good used as an input in steel and iron manufacturing, which are later used as inputs in engineering commodities manufacturing.

intensive industries, such as construction (including infrastructure and urbanization), transportation (including railways, shipping, automobiles), and machinery (Smil, 2017).

Table 5 presents the industries included in the energy-core category in this study, based on the sectoral categorization of the London Stock Exchange (LSE) offered by Michie (1999:88), and according to their year of appearance in the LSE, and based on the categorization of the 1907 British Census of Production (Census of Production, 1907) and the UK Standard Industrial Classification (Central Statistical Office, 1968).

Table 5: Energy-core industries categorization by period and measure class

Measure Class	***Period***	***Industries***
National accounts based	1871-1913	Ferrous metals manufacturing Engineering Commodities (including electrical engineering and services) Mining and Quarrying
	1920-1938	As above Chemicals and allied trades Shipbuilding Vehicles Treatment of non-metalliferous mining products (e.g., cement) Gas Electricity
London Stock Exchange based	1873-1913	Iron, coal, and steel Gas Mines Shipping
	1913	As above, Oil Nitrates Electricity

In terms of transitional processes, I concentrate of the industrial diffusion of steam power, and on pig-iron production related measures. Pig-iron was selected to represent the development of energy-core industries as it is an energy-intensive intermediate good used as an input in steel and iron manufacturing, which are later used as inputs in engineering commodities manufacturing.

For the German *Energiewende* case study, I focus on the generation segment for which the impact of decarbonisation is the strongest and in which most transitional processes occur.[71] Within this segment, I concentrate on German conventional electricity generation firms, studying them in relation to alternative energy generation firms. The major socio-technical changes in the German electricity system include subsidised VER and decentralised energy resources penetration, and legacy-fuel decommission. In addition, dominant electric utility firms are still overwhelmingly centred on conventional generation (Kungel & Geels, 2018). I assume that differential, rather than absolute, measures account for power dynamics. Thus, to study power dynamics within the sector, I organise electricity generation into four categories which reflect the major conflictual changes in the generation segment, and the restructuring of social relations therein.

The first pair of categories, shown in Table 6, differentiates alternative from conventional electricity generation, based on technology and resource-related characteristics. The categories were devised in accordance with major changes affecting sectoral structure. Thus, the significant techno-social features of Conventional Electricity Generation (CEG) include dispatchability and heritage, while in Alternative Electricity Generation (AEG) our focus is on variability and public subsidy.

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[71] Whereas the transmission and distribution segments are also significantly affected by VER penetration's impact on grid stability and reliability, they remain regulated monopolies and are thus able to pass on costs to consumers and earn stable returns.

The second pair of categories differentiate between dominant and non-dominant firms in electricity generation. Here too, the division is not as straightforward as it may seem initially. By ‘dominant firms’ I refer either to the three firms with the largest market share in electricity generation (dominant 3): RWE, LEAG, EnBW; or to five firms by adding E.ON and Vattenfall (dominant 5) (BnetzA, 2022:49-52; Bundeskartellamt, 2023) (see Section 3.7.2.3). For further details on the subsidiaries of dominant firms see Appendix 2.

Table 6: Socio-technical categories in electricity generation

Category	***Resource/Technology***
Alternative Electricity Generation (AEG)	Onshore wind Offshore wind Solar PV Geothermal Biomass Waste
Conventional Electricity Generation (CEG)	Hard coal Lignite Natural Gas Nuclear Oil Mineral oil products Hydro

In practice, different measures include slight variations in the division outlined in Table 6, due to data availability considerations. Nevertheless, the core assignment of variable energy resources (wind and solar) to AEG and fossil fuels and nuclear to CEG is contained in all the measurements. Appendix 1 details the alternative categorizations of AEG and CEG, and their associated measures. In terms of transitional processes in the German electricity sector, I look at the energy-mix of the German electricity sector in relation to peak-load.[72]

[72] The term energy mix refers to the different primary sources used to generate electricity and their respective shares. The term peak-load denotes the maximum load carried by an electrical power supply system over a given period.

3.9 Data sources

The study integrates the differential analysis of physical data, used to study industrial and techno-physical change, with financial and accounting records data, used to study business processes.

3.9.1 British case study data sources

The pecuniary data for the British case study analysis was taken from several different sources. These include primary sources such as historical British population and production censuses, and secondary sources such as the economic history literature which attempts to compile British historical national accounts series.[73]

The physical energy capture and industrial data was taken from secondary sources such as academic literature on the industrial revolution in the UK and its aftermath from the fields of economic history, history of industry and technology, biophysical economics, energy transition studies, and science and technology studies.

Table 7 summarizes the measures and their respective data sources for the UK 1700-2023 by period.[74]

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[73] When existing estimated measures were insufficient, such as in the case of the engineering commodities series, I used existing data to calculate these measures in different ways, as presented in Appendix 4.4.

[74] Note that while Table 7 presents a full list of data sources, it is not a full list of measures, but rather the basic measures and data sets from which further measures were constructed. To illustrate, while total coal use in ferrous metals manufacturing, and total pig iron production appear in Table 7, the measure total coal use per ton of manufactured pig iron does not, seeing as it does not include additional data sources which do not already appear in the table. The same applies to measures such as business income, which is calculated by deducting labour income from gross value added.

Table 7: UK physical, pecuniary, and national accounts data sources

Measure Class	***Measure***	***Years***	***Source***
Physical energy capture	Exergy	1900-2000	Warr, et al., 2010: Table 1.J. Aggregate Time Series (GDP, Capital, Labour, Exergy, Useful Work and Efficiency)
	Useful Work	1900-2000	Warr, et al., 2010: Table 1.J. Aggregate Time Series (GDP, Capital, Labour, Exergy, Useful Work and Efficiency)
	Energy Conversion Efficiency	1900-2000	Warr, et al., 2010: Table 1.J. Aggregate Time Series (GDP, Capital, Labour, Exergy, Useful Work and Efficiency)
	Coal Output per Capita	1700-2020	Coal output: Ritchie, 2019. "Coal production" [dataset]. Population of GB: Bank of England A millennium of macroeconomic data for the UK The Bank of England's collection of historical macroeconomic and financial statistics: Table A18. Population in the UK and Ireland, 000s, 1086-2016.
	Installed steam engine capacity	1760-1907	Kanefsky, 1979: 338 Table 7.10
	Maximum Steam Engine Conversion Efficiency	1700-1893	Smil, 2017: 243, Figure 5.5. Data extracted by Cleveland & Clifford, 2023
Physical industrial	Installed steam power capacity, by industry	1870-1907	Kanefsky, 1979: 344, Table 7.15.
	British pig iron production	1800-1900	Kennedy, 2020: Appendix 5, supporting data for Figure 4.

Table 7: UK physical, pecuniary, and national accounts data sources – continued

Physical industrial	Total coal use in British iron and steel production	1887-1913	Kennedy, 2020: Appendix 5, supporting data for Figure 2
	British steel production	1840-1920	Brikett, 1922: 151, Table 3.
Pecuniary	Total bond par value to Total loans and advances from UK banks ratio	1880-1920	Corporate bond par value from Coyle & Turner, 2013: Appendix, Table 1b. Loans and advances of UK banks: Sheppard, 1971: Tables A1.1-A1.6. UK Bank Balance Sheets 1880-1966
	Buy to Build indicator	1880-2000	Francis, 2018a: 1, UK Buy to Build dataset.
	Differential total capitalization	1883-1913	Michie, 1999: 88, Table 3.2: Nominal values of securities quoted in the Stock Exchange Official List, 1853-1913 (£m.).
			Michie, 1999: 89, Table 3.3: Nominal values of securities quoted in the Stock Exchange Official List, 1853-1913 (%)
National accounts	Gross Value Added at 1907 constant prices	1870-1913	Lewis, 1967: 118, Appendix III, Table 14: Gross Domestic Product at 1907 constant prices.

Table 7: UK physical, pecuniary, and national accounts data sources – continued

National accounts	Gross Value Added at 1907 constant prices, by industry	1870-1913	Calculated using Total GVA[75] and: Lewis, 1967: 86, Appendix I, Table 5: Weights used for industrial production, Base 1907. and Feinstein, 1972: T111, Table 51: Index of Industrial Production by Main Orders, 1855-1965.
	Engineering commodities GVA[76]	1879-1913	Census of Population, England and Wales, 1911, General report with appendices: appendix C, Table 64: Occupations of Males and Females, p. 264-5. Definition of engineering commodities category is from: Census of Production, 1907, Preliminary Tables, part II: 7. Engineering Factories (including Electrical Engineering), Table I: Output, p. 28-9 Lewis, 1967: 86, Appendix I, Table 5: Weights used for industrial production, Base 1907: "Ferrous Metals Products" Feinstein, 1972: T111, Table 51: Index of Industrial Production by Main Orders, 1855-1965: "Engineering".

[75] *Gross Value Added* is a pecuniary measure representing the total value of goods and services produced in a defined area or industry over a defined period, over and above the costs of goods, and deducting the value of intermediate inputs used in production processes. It is the primary component of GDP, calculated from the output side, to which taxes are added and from which subsidies are deducted (Walton & Dey-Chowdhury, 2018).

[76] Note that while I used the Lewis (1967) / Feinstein (1972) indices to calculate historical GVA series, I found their calculation of the engineering series to be problematic. In its place, I constructed a new calculation for the engineering commodities series and used it throughout the analysis. For further details, see Appendix 4.4.

Table 7: UK physical, pecuniary, and national accounts data sources – continued

National accounts	Labour income	1880-1911	Average annual earnings per worker and number of workers by sector and industry: calculated from Feinstein, 1990: 604, 608-611 Table 3: Manufacturing: number of wage-earners, United Kingdom, 1881 and 1911 and average annual full-employment earnings, 1911, Table 4: Indices of average full-time money earnings by sector, 1880-1913 (1911 = 100), and Table 5: Indices of average full-time earnings, manufacturing, 1880-1913 (1911 = 100). Engineering commodities employees calculated from: Census of Population, England and Wales, 1911, General report with appendices: appendix C, Table 64: Occupations of Males and Females, p. 264-5. TABLE 65: Occupations (Condensed List) of Persons, Males, and Females, p. 274-80 Band of England's (2017) *A millennium of macroeconomic data* dataset (Table A53. Employment by industry, 000s of jobs.)
	Corporate income by industry	1880-1911	Share of trading profit in non-farm income: calculated from Solomou & Thomas, 2019: 49-50, Table A5: Breakdown of Gross Trading Profits and Self Employment income.

Table 7: UK physical, pecuniary, and national accounts data sources – continued

National accounts	Price indices	1880-1913	Mitchell, 1988: 728-34. Table 5 Great Britain Board of Trade, 1903: xxxviii: Unweighted percentage variations in prices: group 1 – coal and metals. In the absence of a price index series for engineering commodities I used engineering average wages calculated from: Feinstein, 1990: 604, 608-611 Table 3: Manufacturing: number of wage-earners, United Kingdom, 1881 and 1911 and average annual full-employment earnings, 1911, Table 4: Indices of average full-time money earnings by sector, 1880-1913 (1911 = 100), and Table 5: Indices of average full-time earnings, manufacturing, 1880-1913 (1911 = 100).
	Trading profits by industry	1920-1938	Feinstein, 1972: T71-T72 – Table 27: GROSS TRADING PROFITS OF COMPANIES, PUBLIC CORPORATIONS, LOCAL AUTHORITY TRADING ENTERPRISES; AND NON-FARM INCOME FROM SELF-EMPLOYMENT, 1920-38 Manufacturing and other Industries.
	Labour income	1920-1938	Calculated from: Chapman & Knight, 1952: 68-123: Tables 38-40 – Mining and quarrying salaries and wages, Table 45 – Manufacturing salaries and wages, and 53 – Utilities salaries and wages.

Table 7: UK physical, pecuniary, and national accounts data sources – continued			
National accounts	Labour income	1920-1938	Feinstein, 1972: T57-T59: Table 22: Income from employment by industry.

3.9.2 German *Energiewende* case study data sources

I contend that to study power in socio-technical transitions the sources cannot be restricted to physical or pecuniary data in isolation. I study physical and pecuniary trends in relation to one another, and construct measures which combine both data classes.

In order to study developments in the German generation segment, I use aggregate accounting records for electricity generation from the German Bureau of Statistics. An overall look at firms' performance is supplied by financial data, while physical data pertains to analysis of generation installations.

Data was collected for the years 2000-2022, to cover the period beginning with the passing of the first Renewable Energy Act (EEG 2000) until today. The pecuniary data for the *Energiewende* case study analysis was taken from several different sources. Accounting records data were obtained from annual reports and other primary sources published by German governmental agencies such as the German Bureau of Statistics (DeStatis), and the Federal Network Agency (BnetzA), as well as the German Working Group on Energy Balances (AGEB). Financial data was obtained via two market data platforms: COMPUSTAT Global, and Eikon Refinitiv Datastream.

The physical data was obtained from both official publications of governmental agencies and ministries such as BnetzA and the German Federal Ministry for Economic Affairs and Climate Protection, and from data platforms such as Statista.com. Table 8 summarizes the data and respective sources by data class and category.

Table 8: Data Classes, Categories and Corresponding Sources

Data Class	***Data Category***	***Data Source***
Accounting Records	Revenues from Power Generation by company size Fuel Price for Electricity Generation Export Revenue Import Costs Total EEG Remuneration Total EEG Market Value	DeStatis[1] AGEB[2] BnetzA[3]
Financial Data	Market Capitalization Total Return Indices	COMPUSTAT Global[4] Eikon Refinitiv Datastream
Physical Data	Total net generation Total net nominal generation capacity Annual Peak Hourly Load Conventional Peak Load Fuel Use in Electricity Generation Electricity consumption	BnetzA BMWK[5] AGEB Statista[6] Fraunhofer ISE[7]

[1] Deutsche Statistische Bundesamt. [2] AG Energiebilanzen e.V. [3] Bundesnetzargentur.
[4] COMPUSTAT was accessed through Wharton Research Data Services. [5] Bundesministerium für Wirtschaft und Klimaschutz. [6] Statista was accessed through Tel Aviv University Libraries.
[7] Data was retrieved from the Fraunhofer ISE site: https://www.energy-charts.info/?l=de&c=DE

For further details about data sources by category and variable see Appendix 3.

In addition, to study trends in spatial and ownership centralization, and renewable penetration rates in the German electricity system, I used data derived from the Marktstammdatenregister (MaStR). MaStR is an open access, online market data registry for the German electricity and gas market managed by the Federal Network Agency (BnetzA), which acts as Germany's core energy market data register online portal. It is mandatory for electricity and gas generation plants and electricity suppliers to be registered in the MaStR, alongside transmission and distribution system operators. Consequently, MaStR contains data on all new and existing, conventional and alternative generation plants connected to the electricity network. A detailed description of how I analysed MaStR data is provided in Section 3.1.1.3.

Finally, qualitative data for the content analysis consists of a set of interviews which I conducted for the purpose of this study and is presented in detail in Section 3.10.2.2.

3.10 Methods

The research uses a mixed-method approach, combining quantitative and qualitative methods in a single study. The deliberate use of multiple methods is a single research design has been practised since the 1950s and formalised as a distinct methodological approach during the late 1980s and 1990s (Creswell, 2009; Dunning et al., 2008; McKim, 2017). Initially advocated as part of the *triangulation approach*, the combined use of both quantitative and qualitative data and methods was at first practised to confirm research results. However, the mixed-method approach has evolved as a means to "also gain a better understanding (comprehension) of results, discover new perspectives, or develop new measurement tools" (Dunning et al., 2008: 147). Creswell (2009) suggests that a mixed-methods approach may be used to compensate for the inadequacy of using solely a quantitative or qualitative approach, or if both approaches prove beneficial in enhancing our understanding of a phenomenon.

I find that all the reasonings presented above apply to the questions and phenomena explored in this study, making it appropriate for a mixed-methods research design. Energy transitions are complex socio-technical phenomena, and I seek to study them from the perspective of social power and techno-physical change, implying the need to collect and analyse very different data types.

In the first place, a mixed-methods approach enables me to confirm and validate the results of our quantitative analysis. Abowitz and Toole (2010) suggest that “utilizing two or more data collection methods whose validity and reliability problems counterbalance each other, enables us to triangulate in on the "true" result" (Abowitz & Toole, 2010: 112). Several results based on my quantitative analysis required further validation. For example, an analysis similar to the quantitative analysis I performed on the Marktstammdatenregister (MaStR) generation facility register[77] has, to my knowledge, never been carried out before, making it harder to assess the validity of the trends I discovered. In addition, the registry dataset includes over four million entries, complicating the categorization and aggregation processes. In-depth expert interviews enabled me to examine these results against the knowledge and insights of experts in the field.

Secondly, combining in-depth interview content analysis with quantitative research helped me to appraise and deepen my interpretation of the results of the quantitative analysis, especially in cases where data in higher resolution could not be obtained. For example, data series on revenue by electricity sector segment in Germany were available, and thus I had data on revenues from generation only. However, data on revenues from electricity generation by fuel type proved to be unobtainable. Consequently, using quantitative analysis enabled me to uncover centralization trends in the appropriation of conventional electricity generation revenues, and increasing differential prices for conventional generation. Nevertheless, using

[77] The MaStR is an online registry of all electricity generation facilities in Germany.

quantitative analysis alone, I could not trace the details of the mechanisms behind these price rises and centralization trends over which I could only speculate. In-depth interviews with key business and industry actors in the German electricity sector enabled me to gain a deeper understanding of the trends I uncovered and a more detailed account of the process.

A hallmark of the CasP approach is that it enables us to study complex social power and business-industry dynamics as they are denominated in differential prices. Nevertheless, Joseph Baines (2014) points out that “these quantitative phenomena are best understood with reference to a qualitative analysis of social struggles around the restructuring of society and nature” (Baines, 2014: 4). Complementing quantitative analysis with in-depth qualitative content analysis allowed me both to delve into the specifics of how socio-technical systems are capitalized and how these processes are contested, and to engage with the basic assumption that their differential pecuniary measures represent quantifications of power dynamics. Hence, the study combines both the quantitative analysis of financial, accounting, and physical data, and content analysis of in-depth interviews with experts and business and industry actors engaged in the transition of the German electricity system.

3.10.1 Quantitative analysis measures

I used quantitative national accounts, physical, and financial data to explore the first group of hypotheses, using descriptive statistics and a set of designated differential measures constructed to analyse the co-evolution of trends in energy capture, business strategy, and socio-technical innovation in the context of the two case studies.

The second group of hypotheses was explored using quantitative differential analysis of financial, accounting, and physical data. I then used the content analysis to both confirm the results of the quantitative analysis and their interpretation, and to gain insights about issues for which I lacked quantitative data and to deepen our understanding of the studied phenomena. I used the descriptive statistics analysis of the MaStR electricity installation registry (see Section 3.1.1.3 and Appendix 6) to gain an understanding of trends in centralization, renewable penetration, and sectoral ownership structure.

The two following sub-sections describe the measures, technical terms, and variables used in the quantitative analysis, by case study.

3.10.1.1 British case study quantitative measures and variables

The framework and hypotheses anticipate two main convergences:

Increased energy capture rates expressed as higher primary energy use per capita and conversion efficiency correspond to increased greenfield investment rates and coincide with innovation clusters and the advent of new energy regimes.

Stagnant techno-physical energy capture conditions expressed as lower rates of change in primary energy use and conversion efficiency correspond to increases in M&A activity in energy-core industries and decreased fixed capital investment, coinciding with energy regime reproduction path-dependency.

The British case study analysis can be divided into two periods: before and after the onset of WWI. Hence, the first and major part of the analysis centres on the differential rise of energy-core businesses during the turn of the 20th century. The second, complementary, part of the analysis focuses on the indicators of energy-core businesses' differential performance in the period between the two world wars, and on tracing broad business-industry-energy relations throughout the 20th century. The measures can be broadly divided into three categories: 1. Broad physical energy capture measures and techno-physical industrial measures, which represent the *general* techno-physical development of the British energy regime; 2. Differential pecuniary measures which are based on national accounts and financial data and are used to study developments in social power accumulation and business conditions; and 3. Energy-core business-industry measures which are based on both physical and pecuniary data and are used to study the development of business control of industry in the energy-core sectors, and relations between changing industrial conditions and business pathways. The integrated study of these three analytical categories is the tentative basis for a comprehensive investigation of the coupled changes in energy capture systems and social power accumulation regimes in Britain during the second half of the 19th century and the turn of the 20th century.

The initial stage of analysis traces the socio-technical trajectory of the transition to fossil fuels and maturation of capitalism. To this end, I used first and second category measures to study the development of core techno-physical and institutional features of these processes, respectively. In the second stage, I explored the rise of energy-core businesses under the conditions delineated in the first stage using second category measures. The third stage of analysis delved into business-industry dynamics within the energy-core using third category measures. In the fourth and final stage of the analysis, I used second category measures to study the second stage of energy-core differential accumulation, and a combination of first and second category measures to trace broad patterns in the dynamics of socio-technical and power accumulation changes in the 20th century.

The third category of business-industry measures comprises the main methodological innovation in the British case study analysis. The measures are based on Bichler and Nitzan's (2002) conception of differential profit. Bichler and Nitzan (2002) define the breadth and depth of differential profit as organizational size, i.e., basic quantities controlled by the capitalist entity, and elemental power, i.e., the earnings per basic unit of operation (see Section 2.2.3). To analyse business-industry dynamics in the energy-core sector I constructed two sets of measures: 1. Differential pecuniary measures which deal with *universal* pecuniary representations; and 2. Differential techno-physical pathways which are based on *heterogenous* physical quantities.

The third-category-measure analysis followed three complementary steps: 1. I first turned to Bichler and Nitzan's (2009) formula of differential profit, which defines employees as the basic unit of organization (for further explanations, see Section 2.2.3) to study general differential breadth and depth pathways; 2. I then used output[78] and energy-based measures to study *techno-physical* breadth and depth pathways; 3. Finally, I studied differential pecuniary measures, which represent differential external depth (differential pricing) pathways.

The first step of the course presented above is quite straightforward, as it uses Bichler & Nitzan's (2002) employee-based measures of differential profit.

For the second step of third category-measures analysis I defined energy units as the basic unit of operation. Thus, the differential profit of energy-core firms is studied with regards to their control of energy, and earnings per energy units (see Section 2.2.3). The basic energetic unit of operation is defined as energy inputs in pig iron manufacturing. Pig iron was chosen as the basic manufactured intermediate good in all further ferrous metals manufacturing and engineering commodities production processes. Hence, the first measure of the series calculates profit per ton of manufactured pig iron, and the two following measures break pig iron output down according to the breadth and depth of primary energy input, i.e., total coal use in ferrous metals manufacturing, and coal use per ton of manufactured pig iron, respectively.

[78] Note that when using output-based measures, one cannot differentiate between breadth and depth processes, a rise in output can be an expression of either, or both. To illustrate: both greenfield investment and rising productivity per input/employee might result in increased output.

For the final step of the third category-measures course, I used several differential pecuniary measures: 1. Differential output prices, calculated as the ratio of different disaggregate price indices to the general price index; 2. Differential output/input-prices; and 3. Differential prices/wages.

Table 9 summarises the measures by category, their purpose within the analytical framework, their mathematical formula or verbal description, and a reference to a more detailed explanation of the measure in the appendices.

Table 9: British case study quantitative measures

Category	*Measure*	*Description*	*Years*	*Purpose*	*Reference*
Physical energy capture	Exergy (rate of change)	The component of energy which can perform useful work	1900-2000	A broad measure of energy capture breadth	Appendix 4.1
	Useful work (rate of change)	$\sum physical\ work$	1900-2000	A broad measure of energy capture	Appendix 4.1
	Energy conversion efficiency (rate of change)	$\frac{Useful\ work}{Energy\ inputs}$	1900-2000	A broad measure of energy capture depth	Appendix 4.1
	Coal output per capita (rate of change)	$\frac{Coal\ Output}{Population}$	1760-1913	A measure of energy capture breadth in the transition to steam	Appendix 4.1 Equation 4
	Maximum steam engine conversion efficiency (rate of change)	Expressed as thermal efficiency – the ratio of net work output to heat input.	1700-1900	A measure of energy capture depth in the transition to steam	Appendix 4.1

Table 9: British case study quantitative measures – continued

Physical energy capture	Installed Industrial steam engine capacity	The measure expresses the diffusion of steam power in British industry	1760-1907	A measure of the transition to steam in British industry	Appendix 4.1
	UK pig iron production	Presented in imperial tons	1800-1913	A measure of the output of a basic energy-core intermediate good	Appendix 4.1
	UK steel production	Presented in metric tonnes	1873-1917	A measure of a higher-level energy-core intermediate good	Appendix 4.1
Differential pecuniary – financial and national accounts data	Bonds / Loans ratio	$\frac{Total\ bond\ par\ value}{Total\ loans\ \&\ advances}$	1880-1920	A measure of institutional change - British industrial corporations' relative reliance on the banking sector in financing investments	Appendix 4.2 Equation 6
	Buy to Build indicator	$\frac{Total\ M\&A\ value}{Total\ GFCF}$	1900-2000	A measure of institutional change - The measure represents the relative reliance of business on internal vs external depth measures	Appendix 4.2

Table 9: British case study quantitative measures - continued

Differential pecuniary – financial and national accounts data	Gross Value Added, by industry	The estimated "value" of goods and services produced by a certain industry or sector over and above the cost of its inputs	1871-1913	A differential accumulation measure - the measure (expressed in constant prices) gives an indication of the differential growth of industries	Appendix 4.2
	Differential business and corporate income	$\frac{BI_{Industry\ specific}}{Total\ M\&M\ BI}$	1881-1913	A differential accumulation measure - An indicator of differential profit	Appendix 4.2 Equation 7 Equation 8 Equation 9 Equation 10
	Share of total LSE capitalization	The share of the total nominal value of energy-core firms' securities in the total nominal value of securities listed on the London Stock Exchange	1873-1913	A measure of the development the of energy-core's differential accumulation	Appendix 4.2
	Big energy-core firms' differential performance	$\frac{Energy\ core\ market\ cap}{M\&M\ BI}$	1873-1913	A proxy of the differential performance of big energy-core firms	Appendix 4.2
	Differential trading profits	$\frac{Profits_{Industry\ specific}}{Non\ agricultural\ profits}$	1920-1938	A measure of the energy-core's second stage of differential accumulation	Appendix 4.2

Table 9: British case study quantitative measures - continued

Differential pecuniary – financial and national accounts data	Differential profit margins	$\frac{PM_{Industry\ specific}}{Non\ agricultural\ PM}$	1920-1938	A measure of the source of energy-core's second stage of differential accumulation	Appendix 4.2 Equation 11
Energy-core business-industry	Installed steam engine capacity, by industry	This measure is expressed in absolute terms, as a share of total industrial installed steam engine capacity, and in terms of compound annual growth rates	1870-1907	A measure of the internal techno-physical distribution of the transition to steam in British industry	Appendix 4.3
	Differential employment (employment based)	$\frac{employees_{Industry\ specific}}{Total\ M\&M\ employees}$	1871-1913	A measure of differential depth	Appendix 4.3 Equation 12
	Differential income per employee	$\frac{\frac{BI}{Employee_{industry}}}{\frac{BI}{Employee_{M\&M}}}$	1881-1913	A measure of differential depth	Appendix 4.3 Equation 13
	Output per employee, by industry	$\frac{Output\ (index)}{Employees\ (index)}$	1971-1913	A measure of depth	Appendix 4.3
	Industry-specific share in total industrial coal use	$\frac{Coal\ use_{\ iron\ \&\ steel}}{Total\ M\&M\ coal\ use} * 100$	1849-1913	A measure of energetic relative breadth	Appendix 4.3
	Output per coal use	$\frac{Pig\ iron\ production}{Coal\ use_{\ iron\ \&\ steel}}$	1871-1913	A measure of energetic depth	Appendix 4.3
	Energy-core income per basic input	$\frac{Ferrous\ metals\ BI}{Pig\ iron\ production}$	1887-1913	A measure of profit per basic unit of operation	Appendix 4.3 Equation 14

Table 9: British case study quantitative measures - continued

Energy-core business-industry	Energetic external breadth (rate of change)	Total coal use in ferrous metals manufacturing	1887-1913	A measure of the energy-cores' control of primary energy input quantities – the basic energy units of operation	Appendix 4.3 Equation 15
	Energetic internal depth (rate of change)	$\frac{Coal\ use\ in\ ferrous\ metals}{Pig\ iron\ production}$	1887-1913	A measure of the intensity of coal use in ferrous metals manufacturing, implying changes in energy productivity, an internal depth pathway	Appendix 4.3 Equation 16
	Differential output prices	$\frac{Price\ index_1}{Price\ index_{general}}$	1971-1913	A measure of differential external depth – differential inflation	Appendix 4.3 Equation 17
	Differential coal and iron prices	$\frac{Pig\ iron\ price\ index}{Coal\ price\ index}$	1880-1913	A measure of the energy-core's ability to raise profit margins by raising output prices in relation to input prices	Appendix 4.3 Equation 18
	Differential iron prices and wages in iron and steel manufacturing	$\frac{Pig\ iron\ price\ index}{ferrous\ metals\ avg.wage}$	1880-1913	A measure of the energy-core's ability to raise profit margins by raising output prices in relation to wages	Appendix 4.3 Equation 19

3.10.1.2 German *Energiewende* case study quantitative measures and variables

The second quantitative endeavour includes an empirical analysis of the interrelated processes of socio-technical change and social power redistribution using the German *Energiewende* case study. It is concerned with the second group of hypotheses.

Building on CasP theory (Nitzan & Bichler, 2009), I developed and employed four conceptual tools for the empirical study of organised power in the transitioning German electricity sector. The tools combine physical and pecuniary analysis to study the ways in which dominant conventional electricity generation firms attempt to leverage techno-physical changes in the German electricity system to increase their sectoral control, and the implications this might have for transitional pathways. I contend that in order to understand social power in energy transition, and its limits, all three aspects of business-industry-energy relations must be studied: using differential pecuniary data to represent business management, which is concerned with private profit and therefore with distribution; techno-physical data to represent industrial changes and tecno-physical limits; and policy analysis to understand the regulatory framework through which public policy directs, restricts, and enables industrial change.

Following an initial stage in which I used financial measures to identify a rise in the differential accumulation of German conventional energy firms, I developed four sets of measures which combine physical, financial, and accounting records data for the purpose of this study: The first set of measures study the basic question - how much do businesses receive for a unit of generated electricity?; The second measure is used to study the degree to which conventional electricity generation and dominant firms can threaten reliable electricity supply by "holding back" conventional generation; The third set of measures is used to study the volume of forward contracts in electricity sales, and the degree to which these are used in comparison to spot market contracts; The fourth and final measure is an expression of the share of big firms' revenue in the total revenue from conventional generation, and used to study centralization trends in the control of conventional electricity generation. These measures trace the story of dominant German CEG firms' regaining of sectoral control.

First, using the first set of measures, the differential tariff is used to study the development of differential depth – i.e., the rise in profit per basic energetic unit of operation (generated electricity in kWh). Then, using the second set of measures, I trace the techno-physical conditions of the transitioning German electricity system which put those who control flexible electricity generation in the position to leverage a threat to the system. Later, using the third measure, I determine the degree to which CEG firms leverage the alleged threat to negotiate higher prices on forward contracts. And finally, using the fourth measure, I study centralization processes in the control of CEG.

Table 10 summarises the measures, their purpose within the analytical framework, their mathematical formula or verbal description, and a reference to a more detailed explanation of the measure in the appendices.

Table 10: German Energiewende case study quantitative measures

Measure	***Description***	***Years***	***Purpose***	***Reference***
The differential tariff 1 - Conventional electricity	$\frac{CEG\ revenue}{total\ net\ CEG}$	2011-2021	A measure differential depth – revenue per basic unit of operation	Appendix 5.1 Equation 24
The differential tariff 2 - Alternative electricity	$\frac{EEG\ Renumeration}{EEG\ Eligible\ Generation}$	2011-2021	A measure differential depth – revenue per basic unit of operation	Appendix 5.1 Equation 25
Conventional electricity gross profit proxy	$Conventional\ generation\ revenue - fuel\ costs$	2011-2021	A measure differential depth – profits per basic unit of operation	Appendix 5.1 Equation 27
Conventional capacity to peak hourly load	$\frac{Conventional\ Installed\ Capacity}{Annual\ Peak\ Hourly\ Load}$	2013-2021	A measure of conventional electricity generation potential threat to reliable supply	Appendix 5.2 Equation 28
Electricity sales to revenue from electricity generation ratio	$\frac{Total\ electricity\ sales}{Annual\ generation\ revenue}$	2011-2021	A measure of the reliance on forward contracts in relation to spot market contracts in electricity sales – the sales-strategy expression of the leverage of conventional threat to reliable supply	Appendix 5.3 Equation 29
Conventional electricity generation revenue centralization	$\frac{Big\ conventional\ firms\ revenue}{Total\ conventional\ revenue}$	2006-2020	A measure of the share of conventional generation revenues appropriated by large firms	Appendix 5.4 Equation 30

3.10.1.2.1 MaStR database analysis of renewable energy penetration trends

The German Energiewende case study included a second quantitative endeavour, in which I used Marktstammdatenregister (MaStR) data to study penetration rates and trends in spatial and ownership centralization in RES. There are over 4 million electricity generation facilities registered on MaStR, with a commission year span ranging from 1900-2021 (updating). I downloaded all the entries and uploaded them to SNOWFLAKE database. Using SQL queries, I aggregated the data annually, grouped by the categories shown in Table 11. For further details on the categorization queries, see Appendix 6.

Table 11: Aggregation Categories and Values for MaStR database

Category	***Values***
Commission Date	1900-2021
Operator Type	Person Firm Cooperative e.K e.V GbR OHG Public Other
Capacity Class	Small < 100 kW Large > 100 kW Utility > 1 MW Legacy > 500 MW
Energy Class	Alternative Conventional
Energy Source Class	Renewable Fossil Other
Is Dominant Operator	0 1
Net Capacity	In kW

After aggregating the data, I exported the aggregated data as a CSV file and imported it into R, in which all further analysis was performed.

A cumulative installed capacity sum was then computed for each year by category. This was done by summing all commissioned installed capacity up to a given year and then subtracting the sum of decommissioned capacity.

Three main variables inform the analysis of techno-physical and ownership centralization trends in Germany: 1. Alternative energy resources installed capacity by ownership type, which gives an indication of the changing ownership structure of RES; 2. RES plant size, which gives an indication of changes in the techno-spatial centralization of RES capacities; 3. RES penetration rates, calculated as the share of RES in total installed capacity.

Table 12 summarises the measures, their purpose within the analytical framework, their mathematical formula or verbal description. A more detailed explanation of the measure can be found in Appendix 6.

Table 12: Measures of renewable energy sources techno-physical and ownership centralization, and penetration rates.

Measure	***Description***	***Years***	***Purpose***
Alternative energy resources installed capacity by ownership type	Differentiates between corporate owned and prosumer installed RES capacity	1990-2021	A measure of ownership structure of RES in the German electricity system
Alternative energy resources installed capacity by plant size	Differentiates between installations by three installed capacity categories - small, large, and utility scale	1990-2021	A measure of the techno-spatial distribution of RES installed capacity in the German electricity system
Renewable energy sources penetration rate	$\frac{Total\ RES\ installed\ capacity}{Total\ installed\ capacity}$	2004-2021	A measure of the rate of decarbonization of the German electricity system

3.10.2 Qualitative

In this section I present the qualitative part of the mixed-methods research. This study was carried out in the context of the contemporary German *Energiewende* case study. The qualitative method I used is content analysis of in-depth interviews. I interviewed business representatives, experts, and key actors from three different areas of the transitioning German electricity sector, namely: 1. Representatives of the four major conventional electricity generation firms; 2. Representatives of the BDEW – the German association of energy and water industries; and 3. representatives of two of the four German transmission system operator firms.

I had two objectives in performing and analysing in-depth-interviews:

1. *To assess the results of the quantitative analysis and their interpretation*.

   This objective regards the second group of hypotheses. In this case I used expert-interviews, asking interviewees for their opinion and insights on results I obtained and the way I interpreted them.

2. *To gain insights regarding processes for which quantitative data is lacking.*

   This objective also regards the second group of hypotheses. In this case I used expert-interviews to gain insights on the details of business-industry dynamics which were discovered using quantitative analysis. In addition, I used interviews to gain leads for further quantitative investigation.

3.10.2.1 Content Analysis Methods

Content analysis involves strategies of textual coding, recording of comments and memos, developing categories, and, ultimately, theorizing the relations between them (Charmaz, 2019;

Hernandez, 2009). Hsieh and Shannon (2005) differentiate between three approaches to content analysis, namely, the conventional, directed, and summative approaches.

In *the conventional approach* to content analysis the researcher derives coding categories directly from the data in order to formulate a theory. Graneheim et al. (2017) also refer to this approach as data-driven, or inductive.

In contrast, a *directed approach* uses existing theory or relevant research findings to predefine key concepts and coding categories later explored in the text. Graneheim et al. (2017) also refer to this approach as concept-driven, or deductive.

Finally, *summative content analysis* refers to a process of "counting and comparisons, usually of keywords or content" as in quantitative content analysis, yet this is "followed by the interpretation of the underlying context" (Hsieh & Shannon, 2005: 1277).

I used both a conventional and directed approach to analysing the textual data. Focusing on the second group of hypotheses, I used a directed approach, leaning on key concepts and codes which were derived from the conceptual framework and from the results of the quantitative analysis and seeking both to assess our findings and assumed relations, and to deepen our understanding of these relations. Nevertheless, I also performed a separate, undirected, coding of the texts to identify the key concepts which organically arise from them, and the relations between them.

The qualitative content analysis was carried out according to the following steps, derived from White and Marsh (2006):

1. Data collection: In-depth interviews

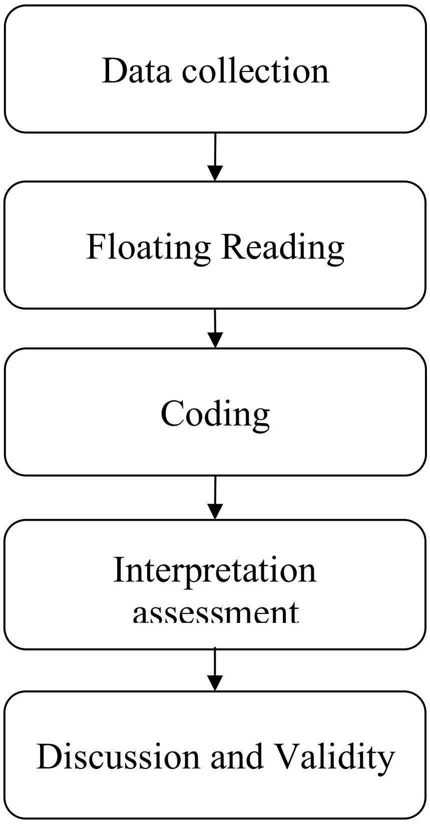
2. Floating reading: frequent re-reading of the textual data to familiarise oneself with it, and to attain an understanding of the "bigger picture" emerging from it.

3. Coding: identifying emergent concepts, interpretations, and ideas. Identifying relations between the text and existing categories, predefined by the results of the quantitative analysis. Recording of content and theory memos to track the process of interpretation and conceptualisation.

4. Interpretation assessment: reassessing interpretation against documents, notes and theory.

5. Discussion and validity: discussion of results and their validity according to measures of credibility, dependability, and transferability (Graneheim et al., 2017; White & Marsh, 2006:37-40).

Figure 3: Conventional content analysis outline



Achieving *credibility* involves the selection of experts and key actors in social processes as informants, as well as achieving a sufficient number of informants in order to reach saturation, the point at which ideas, concepts and insights begin to repeat themselves (Saunders, et al. 2018).

Achieving *dependability* involves creating clear rules to construct and differentiate between categories. In addition, it involves reflecting on the researcher's preconceptions and potential influence on the produced empirical text (Graneheim et al., 2017).

Transferability refers to whether findings can be "applied to other, comparable contexts" (White & Marsh, 2006: 38).

3.10.2.2 In-depth Interviews and Informants

I performed a series of nine in-depth interviews, with ten informants from the German electricity sector.

Most interviews spanned between an hour and 90 minutes, and two were between 35 and 45 minutes long. The interviews were held and recorded via the Zoom Meetings software program. The recordings were transcribed soon after they were held, and comments and memos from the interview were also documented.

The interviewees can be divided into three groups: Transmission System Operator (TSO) representatives, large Conventional Electricity Generation (CEG) firms' representatives, and Federal Association of the Energy and Water Industry (Bundesverband der Energie und Wasserwirtschaft e.V., BDEW) representatives. From the BDEW I interviewed three employees: a policy advisor, a senior executive at the Economics department, and an employee of the Strategy and Policy Division; From the CEG segment I interviewed four representatives of the four largest CEG firms in Germany: three senior managers, and a senior policy advisor; and from the TSO's I interviewed three representatives from two of the four TSO companies in Germany: a senior manager, a senior policy advisor, and a press and policy department employee, and received answers in written form from a vertical grid load manager. For further information on the interviewees, see Appendix 13.

In effect I interviewed representatives of all large German CEG firms, save one which refused my interview request. I also interviewed representatives of two out of four TSOs in Germany, which work in tight cooperation and with high agreement regarding *Energiewende* policy, seeing as the grid is, altogether, an integrated system. From the BDEW I interviewed three representatives of different departments and organizational functions, which work with electricity sector firms, German government actors, as well as EU-level actors. In this respect they have a view of the wider picture of *Energiewende* policy and decision-making processes, as well as the different interests within the electricity sector. Many of the interviewees (five) held their positions for long periods of 10-20 years and above and thus could give a fist hand account of different stages in the transitional process. Most interviewees (seven) hold a senior or executive position within their respective company or organization and thus could supply detailed and informed answers to my questions, as well as novel insights on the subject matter. I decided that the interviewing stage had reached exhaustion when codes, categories and arguments began densely reappearing in the texts, indicating saturation, and when I had completed interviewing at least one representative of each company or organization which consented to participating in the research. These conditions apply to the *credibility* of the analysis. The initial set of questions I devised for the interviews is fully reproduced in Appendix 7. These questions were later selected from, added to, and altered to benefit each informant and context. Questions and topics also naturally evolved in the course of the interview and in response to the informants' input. All interview transcriptions can be found in the project's OSF account: https://osf.io/rdpy6/?view_only=be6f336809f24cce9dfe49ad2d1bd0f9.

Table 13 presents a list of codes and categories derived from the quantitative analysis results and analytical framework, in accordance with the *directed approach* to content analysis, and from the interviews themselves, in accordance with the *conventional approach* to content analysis. It also presents a short explanation of how they were identified, in accordance with the principle of *dependability*.

Table 13: Initial content analysis codes and categories

Category	***Differentiation***
Risk and risk perceptions	Deliberate reference to uncertainty, concern, and risk in the wide sense of social, techno-physical, political, and economic considerations
Centralization	References to centralization as an evolving phenomenon, strategy, threat, inevitability
Power	References to ability and disability to act, plan, shape, control, and anticipate unfolding and future developments
Regulation	Perceptions of regulation, risk and regulation, anticipated policies, perceptions of the effects of regulation, and future requirements, strategies in the face of regulation
Strategy	Deliberate and covert references to business strategy, and the tracing of strategic sabotage
Self-perception and positioning	References to the changing self-perceptions of the organizations and their redefinition vis a vis changing conditions
Sales and pricing	Deliberate and covert references to sales and pricing strategies and mechanisms
Investment	Deliberate and covert references to investment strategies, risk perceptions, goals and ability

Table 13: Initial content analysis codes and categories - continued

Control	Deliberate and covert reference to the ability to exert control over a wide range of processes, resources, technologies, decision makers, and the public
Change	Perceptions of social, technological, systemic, and sectoral changes, and of climate change
Threat	Perceptions of overt and covert threats to the German electricity system and to the Energiewende process
Confidence	References to the degree of confidence in strategies, control, perceptions, projections, influence, persistence, ability to face uncertainty, predictability of political and social developments
Technology	Perceptions of technology and industry, and specific references to different technologies

Regarding *transferability,* I contend that the findings of the analysis, and the processes uncovered, can be applied and used to study not only the decarbonisation processes of electricity systems other than the *Energiewende*, but also, with appropriate adjustments, a range of other socio-technical transition processes.

4. The energy-core's seven good years: the shaping of nascent differential accumulation pathways and the transition to fossil fuels

This section presents the results of the British case study analysis, in which I examined the interlinked processes of change in energy capture systems, and social power accumulation regimes in Britain during the second half of the 19th century and the turn of the 20th century. The period represents an era of major changes in both sociotechnical and power accumulation regimes, marked by the gradual maturation of the energy transition to fossil fuels, the emergence of the cluster of related technologies sometimes dubbed the second industrial revolution, and the rise of industrial capitalism (Hannah, 1983; Smil, 2005).

Hypothesis 1 suggests that a combined expansion in the breadth and depth of energy capture is coupled with both internal depth and external breadth strategies and related to transformative socio-technical processes. Studying the historical moment of dual transformation in both energy capture and power accumulation regimes, and its aftermath, enables us to explore the dynamics of changes in societal energy capture and power accumulation strategies during transformative sociotechnical periods, and the proposition presented in this hypothesis.

The analysis results are presented and discussed in four complementary parts. *Section 4.1* traces the techno-physical course of the transition to steam in British industry, outlining its different stages and focusing on the period of maturation during the turn of the 20th century when the industrial transition to coal and steam power reached the asymptotes of change.

Section 4.2 explores the organizational and institutional changes which were set in motion during the second half of the 19th century, i.e., business centralization, corporatization, and the larger use of credit, as part of the consolidation of dominant capital[79] and differential accumulation regimes.

Section 4.3 presents the heart of the findings, delving into an analysis of the differential performance of what I term the *Energy-core*. The energy-core includes the era's energy intensive industries and the primary energy resource industries which sustained them, i.e., mining and quarrying, ferrous metals manufacturing, and engineering commodities to start with, and later chemicals, oil, and nitrates. *Section 4.4* considers the dynamics of power accumulation, energy capture, and sociotechnical change in the aftermath of the transition to fossil-fuels and during the consolidation of the 20th century's prevalent energy and social power regimes.

Using both physical and pecuniary data, I will show that during the turn of the 20th century the slowing down of the rampant transition to fossil fuels accompanied a process in which the energy-core gained *differentially* from greenfield investments and differential cost cutting. The energy-core later leveraged this differential gain in a wave of mergers and acquisitions and big business consolidation.

I will argue that the rare techno-physical context of the energy transition to fossil fuels gave rise to these business-industry dynamics. Perhaps this was the only historical constellation of business and energy capture regimes which could have enabled an energy transformation alongside increased capital and power accumulation concentration, and the confined emergence of external breadth and internal depth as differential accumulation pathways. The transition to fossil fuels and the radical socio-technical changes which accompanied it shifted the focus of business activity from the control of commerce and end-use products to the control of industry and energy-intensive industrial inputs. And although throughout most of the 19th

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[79] The term *dominant capital* refers to the coalition of leading corporations and government organs which support them (Nitzan & Bichler, 2009).

century the rampant pace of socio-technical change prevented nascent dominant capitalist entities from achieving stable differential accumulation, I will show how, as rates of techno-physical change began to decline, early price-shaping mechanisms began to supplement the control of output. During what I will term the energy-core's seven good years of differential accumulation between 1894-1900, the energy-core's differential productivity and size were realized as differential accumulation through differential monetary measures.[80] The differential inflation of the energy-core's output prices in relation to the prices of its two main inputs, labour (wages) and energy (coal prices) resulted in stable differential profit levels for the rising energy-core. In this sense, the ferrous metals manufacturing business and the industry's unions act as forerunners of the prevalent price-making practices of the 20th century, heralding the maturation of the capitalist mode of power.[81]

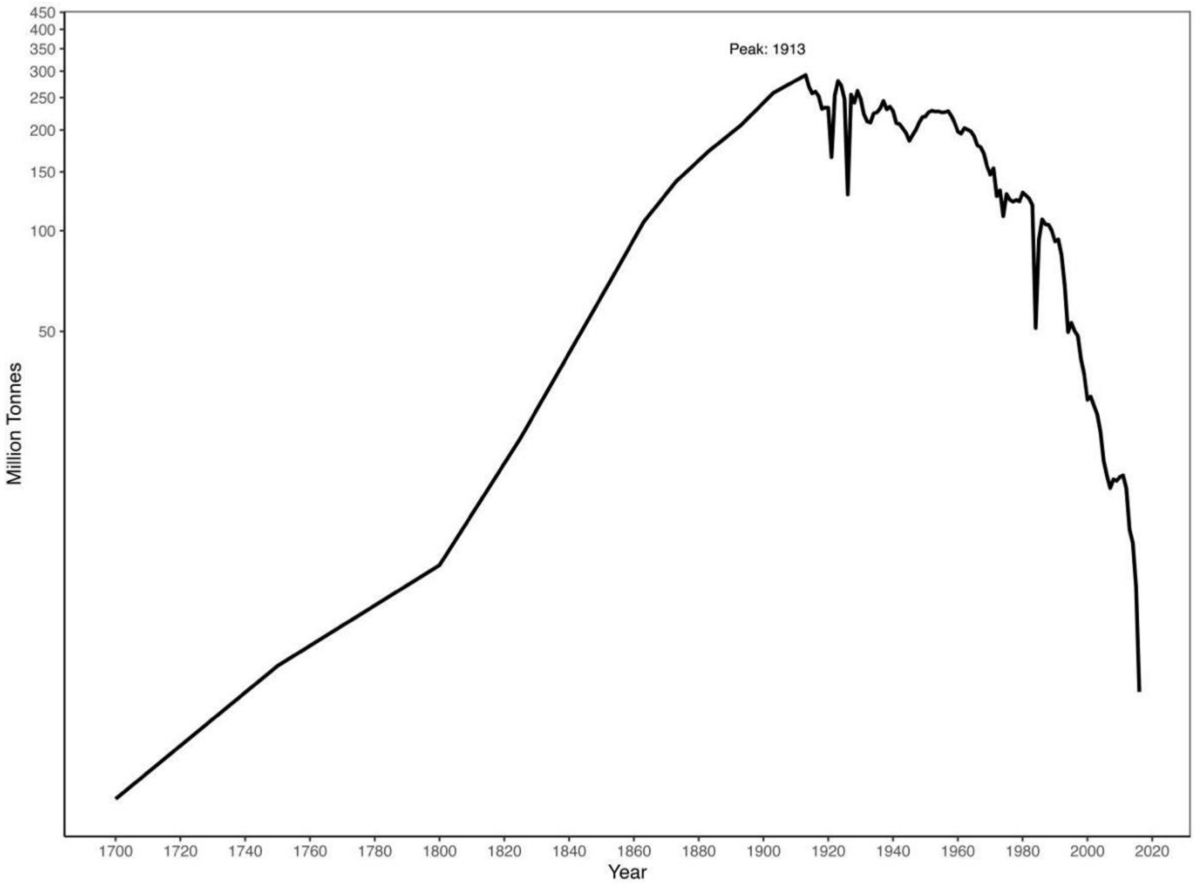
4.1 The 19th century: Changes in energy capture and the transition to fossil fuels

During the 19th century in Britain, a coupled growth in the breadth and depth of energy capture took place (greater deployment of new primary sources and higher EROI,[82] respectively). Figure 4 shows the spectacular growth in British coal output which increased by a factor of 30 in little over a century, from 10 million tonnes in 1800 to over 290 million tonnes when British

[80] Differential monetary measures are treated henceforth as distinct from differential techno-physical pathways.
[81] In contrast to *price-takers*, i.e., firms which must accept the market price, *price-makers* are in the position to set prices to their advantage. While liberal theory insists on imagining firms as price takers with little or no power over market prices, empirical analysis has consistently shown that modern firms are overwhelmingly price makers: they administer the price of their output, rather than passively accepting it (Nitzan & Bichler, 2009; Hall & Hitch, 1939; Means, 1935).
[82] Energy return on investment (EROI) is a measure of the ratio between energy produced and energy used in its production (see Section 2.3).

coal production peaked in 1913. The significant growth in coal production marks not only an increase in the breadth of societal energy capture, but also in its depth. [83]

Figure 4: UK Coal Output, 1700-2016



Note: The figure is plotted with a logarithmic scale on the y axis, to emphasise rates of change.
Source: Ritchie, 2019. "Coal production" [dataset]. Processed by Our World in Data from: UK DECC & Department for Business, Energy & Industrial Strategy (BEIS) [original data].

While coal is characterised by higher energy densities in relation to traditional biofuels,[84] it was developments in the technique of fossil fuel conversion and its uses which brought about the quantitative and qualitative changes in energy capture associated with the energy transition

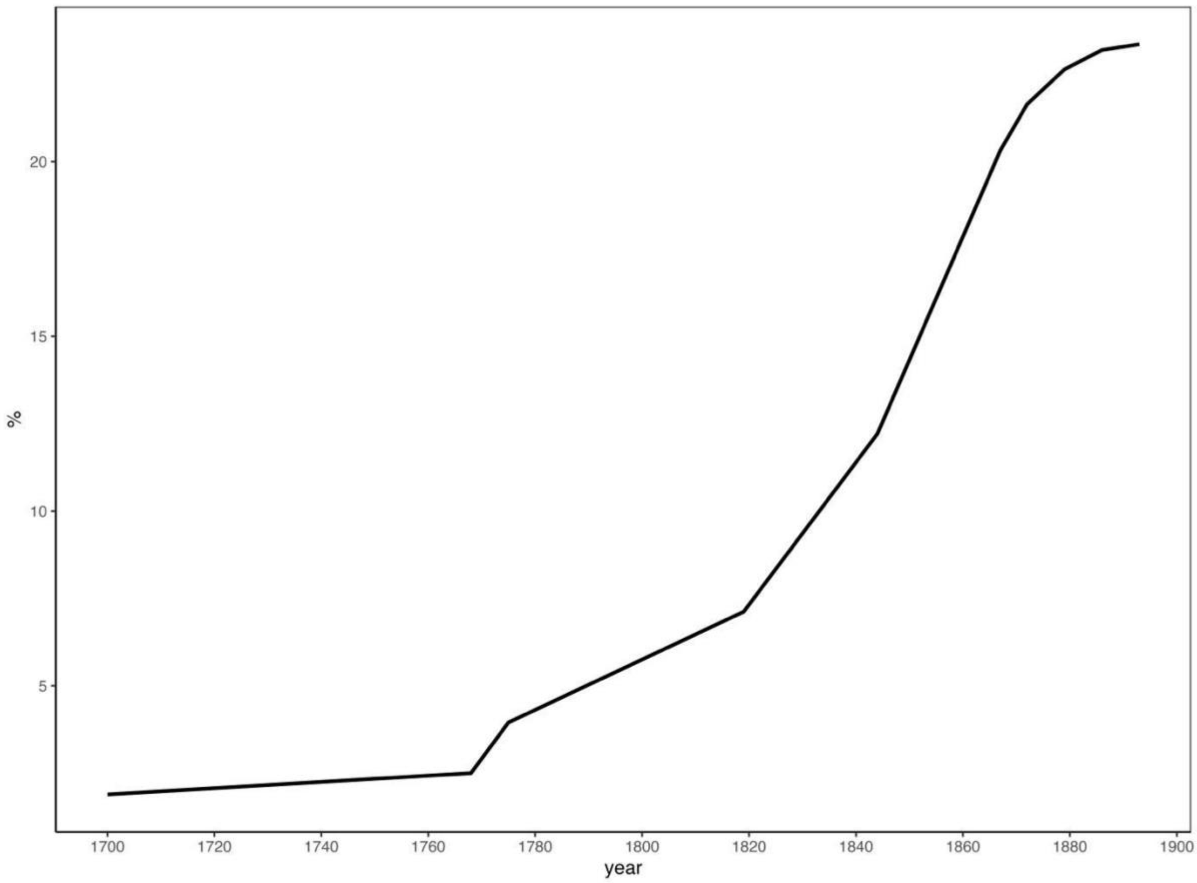
[83] Societal energy capture denotes the full range of primary energy converted by humans into useful energy as well as the energy demanded for this process at the level of the society at large (Morris, 2013).

[84] The energy density of a resource represents the amount of energy per unit mass, volume, or area of a fuel (Smil, 2017). Though energy densities of coal vary widely, they are higher than those of traditional biofuels such as wood. The energy density of anthracites (hard coal) lies between 31-33 Mj/kg and that of Bituminous coal lies between 20-29 Mj/kg (Smil, 2017: 227, Box 5.1), while the energy density of (dry) wood lies between 17-21 Mj/kg, and that of peat lies between 5-10 Mj/kg (Smil, 2017: 12, Box 1.4).

to fossil fuels. Such changes in the depth of energy capture were advanced by the introduction, development, and diffusion of new prime movers (e.g., steam and internal combustion engines, steam and gas turbines), as well as the transformation of raw fuels, and the introduction of substances such as coke and coal gas (Smil, 2017). These in turn, led a qualitative and quantitative change in industries such as metal manufacturing.

Figure 5 depicts the development of maximum steam engine conversion efficiency. Over a period of half a century between 1820-1870 the maximum conversion efficiency of steam engines increased by a factor of 3, rising from 7% to 12% between 1819 - 1844 and then to 21% by 1870.

Figure 5: Maximum steam engine conversion efficiency, Britain, 1700-1893



Source: Smil, 2017: 234, Figure 5.5: Rising power and improving efficiency of the best steam engines, 1700–1930. Data extracted by Cleveland & Clifford, 2023.

Note: The data points were digitized from Smil's visualization of periodic observations. Hence, they are to be viewed as approximations of the original observations.

Yet, as can be seen in Table 14 and Table 15, and in Figure 4, the average annual geometric rate of change in both maximum steam engine conversion efficiency and UK coal production began to decline during the second half of the 19th century: in the case of conversion efficiency, it dropped from 2% to 0.6% during the 1870's and to 0.2% during the 1880's; and in the case of coal production per capita it gradually declined from 2.5% between 1800-1863 to 0.4% between 1903-1913 and turned negative after 1913 (-3.5% between 1914-1920). Note that during the 1890's the declining rates of change in coal output per capita were periodically inverted, and growth rates of coal output per capita seemed to pick up again, before resuming their decline during the early 20th century.

Table 14: Average annual change in maximum steam engine conversion efficiency (geometric mean), Britain, 1830-1893

Year	**Average annual rate of change**
1830-1844	1.9%
1844-1853	2.6%
1853-1870	1.9%
1870-1883	0.6%
1883-1893	0.2%

Source: see Figure 5.

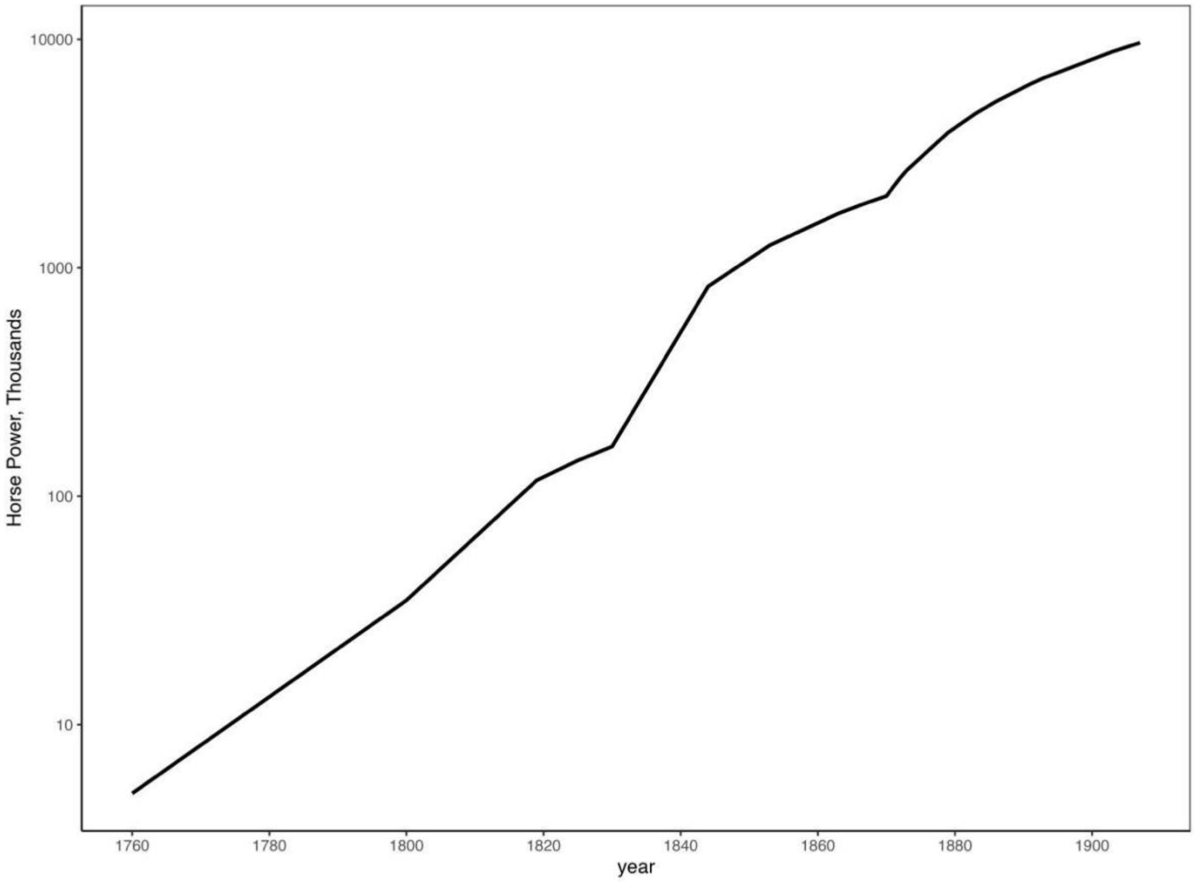
Table 15: Average annual change in UK coal output per capita (geometric mean), 1700-1920

Year	**Average annual rate of change**
1700-1800	1.1%
1800-1863	2.5%
1863-1873	1.5%
1873-1883	0.8%
1883-1893	0.7%
1893-1903	1.1%
1903-1913	0.4%
1913-1920	-3.5%

Source: Coal output: see Figure 4. Population of GB: Bank of England A millennium of macroeconomic data for the UK The Bank of England's collection of historical macroeconomic and financial statistics: Table A18. Population in the UK and Ireland, 000s, 1086-2016.

Figure 6 and Table 16 show a similar trend: an increase in average annual growth rates in the diffusion of steam power in British industry from 5.1% between 1760-1830 to 6.5% between 1830 - 1870; and then reduced average annual growth rates between 1870-1907 (4.3%), falling below the average annual growth rate displayed between 1760-1830.

Figure 6: Installed steam engine capacity, Britain, 1760 - 1907



Note: Figure is plotted with a logarithmic scale on the y axis, to emphasize rates of change.
Source: Kanefsky, 1979: 338 Table 7.10

Table 16: Average annual growth rates of steam engine adoption in British industry, 1760-1907 (geometric mean)

Years	***Average annual rate of Change***
1760-1800	5%
1800-1830	5.3%
1830-1870	6.5%
1870-1907	4.3%

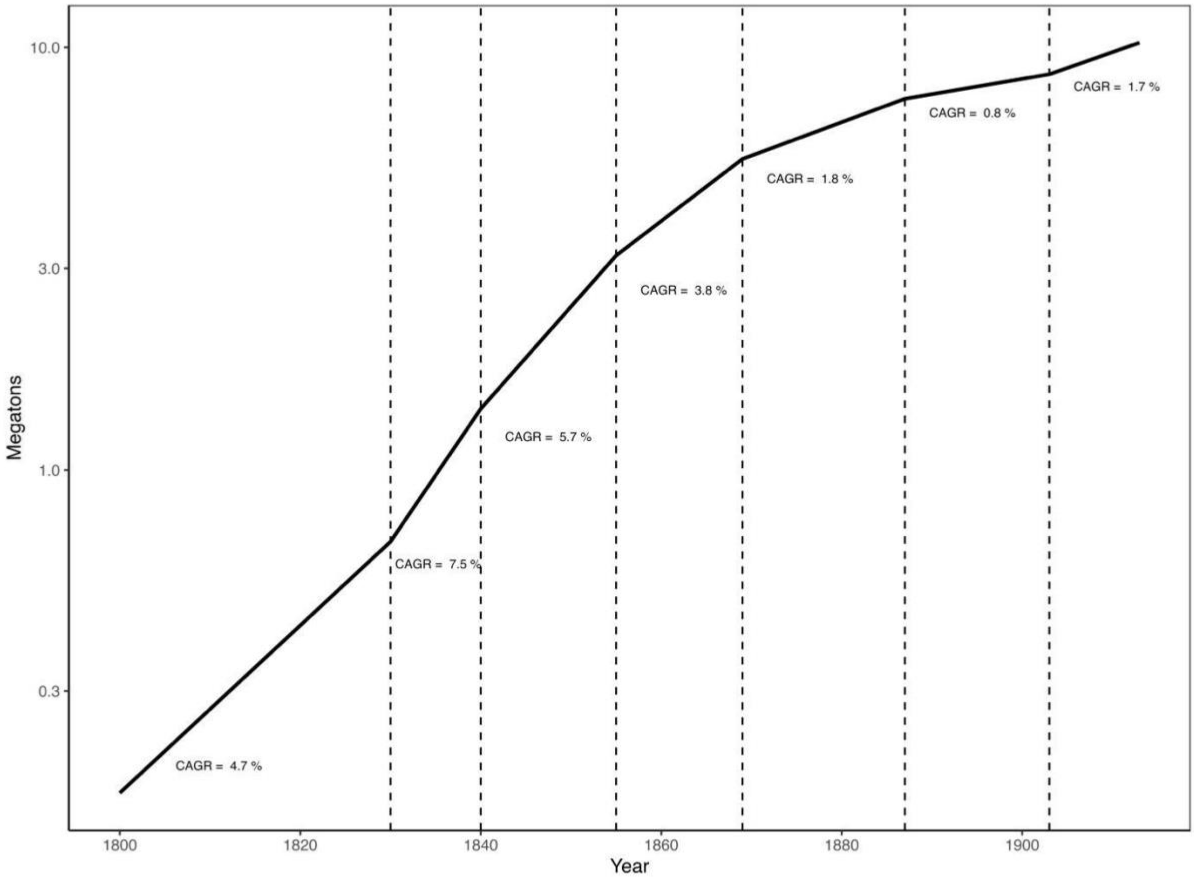
Source: see Figure 6.

It could be argued that the asymptote reached in steam engine conversion efficiency development and the stagnation and later decline in UK coal production correspond to the introduction of a new, and more efficient prime mover - the steam turbine - and of a new, fluid, and more energy dense form of hydrocarbon - crude oil. Yet the stagnation in steam engine conversion efficiency development can be dated to the 1890's only a few years after the appearance of the first steam turbines, which only surpassed steam engines in their conversion efficiencies during the second decade of the 20th century, and with steam engine conversion efficiencies rising again between 1920-1950 (Smil, 2017: 398, Figure 7.4). Coal remained the dominant energy resource in transportation, as well as electricity generation throughout the first half of the 20th century, oil, and later natural gas, adding on rather than replacing it as a major energy resource (Smil, 2017; York & Bell, 2019). In addition, coal played a major role in powering the British empire, its global infrastructure driving the empire's expansion and consolidation (Barak, 2020).

The growth rates of energy-intensive commodities output show similar trends. Much of the growth in industrial primary energy use and conversion efficiency was channelled into the manufacturing processes of these intermediate and final products.

Figure 7 presents total UK pig iron production and its related annual geometric rates of change. It shows a slowing of the rate of growth of pig iron production throughout the second half of the 19th century. Notably, during the period of 1887-1903, the compound annual growth rate dropped by a factor of 2.25 in relation to that of 1869-1887 (which itself halved in relation to the compound annual growth rate of 1855-1869).

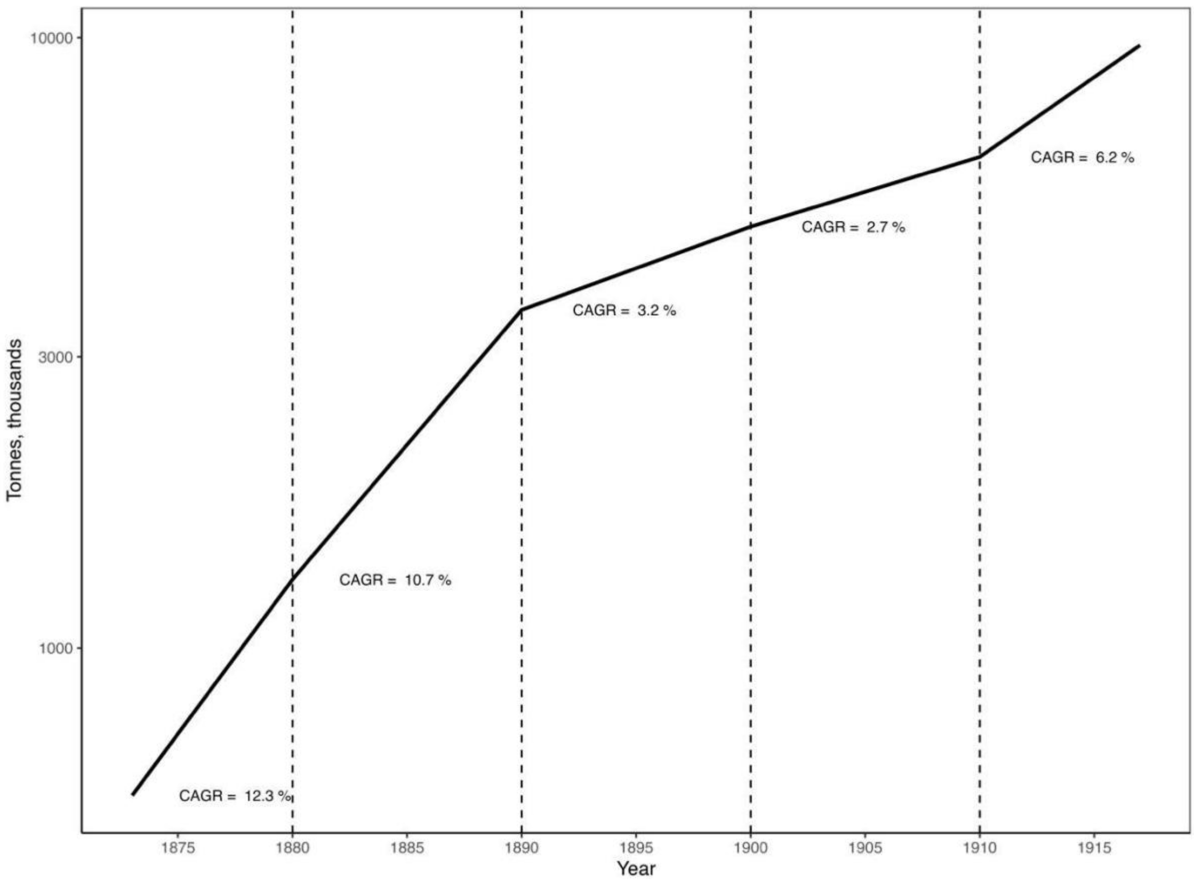
Figure 7: UK Pig Iron Production, 1800-1913



Note: Figure is plotted with a logarithmic scale on the y axis, to emphasize rates of change
Source: UK pig iron production: Kennedy, 2020: Appendix 5, supporting data for Figure 4.

Looking at trends in UK steel production plotted in Figure 8, we see a similar slowing of output growth throughout the late 19th century, and between 1890-1900 in particular, when annual average geometric rates of change dropped to 3.2% from 10.7% the preceding decade.

Figure 8: UK steel production, 1873-1917



Note: Figure is plotted with a logarithmic scale on the y axis, to emphasize rates of change.
Source: Brikett, 1922: 151, Table 3.

As in the course of change presented in the figures above, the logistic curve has been used to illustrate the diffusion of technological innovations and new energy sources. This course includes an initial phase of rapid innovation and growth, followed by a second phase of fast diffusion and sectoral growth, which is continued until full industrial deployment, and finally reaches maturation and the asymptotes of expansion (Perez, 2002).[85] The following analysis explores the relations between these sociotechnical dynamics, the accumulation of social power, and the consolidation of the capitalist mode of power, focusing on the second half of the 19th and turn of the 20th centuries, when the techno-physical course of change entered the

[85] To illustrate, these dynamics are apparent in the rise of the steel industry and process of electrification (see Ayres, 1989: 26, 35 - Figures 8 and 11).

third phase of maturation and retardation of growth rates. I will argue that this phase of the transformative socio-technical process was ripe for the leverage of differential accumulation strategies. Building on significant changes in the breadth and depth of energy capture, the differential performance of energy-core industries gave rise to dominant capital and a new regime of power accumulation. As I will present in detail in the following sections, the crux of this process was a new price-making mechanism which developed within the ferrous metals manufacturing businesses. I will argue that this precursor of the 20th century price-making practices enabled ferrous metals manufacturing businesses to shape and control differential output prices in the general context of fluctuating prices accompanied by steadily rising wage rates.

4.2 Second half of the 19th century: Centralization, corporatization, and the larger use of credit

The techno-physical changes described in the previous section went hand in hand with a gradual reorganisation of the industrial structure and the business form. Up until the second half of the 19th century British industry was characterised by small scale manufacturing. Though some large employers did emerge early, particularly in the textile industry, the overwhelming majority of British manufacturing businesses consisted of small scale, family-based workshops employing up to five workers, apprenticeships, and small own account manufacturers (Hannah, 1983).

The second half of the 19th century brought with it a rapid growth in small, medium and large-scale businesses alike, which Bennett et al. (2020a) attribute to increasing demand resulting from rapid population growth. Thus, while small firms continued to dominate the market, the share and significance of large employers consistently grew (see Section 3.7.1.3).

Moreover, while the average firm size in manufacturing grew from 30 employees in 1861 to 38 employees in 1901 (Bennett et al., 2020b), I calculated that by this year the 438 firms employing over 1,000 workers (a mere 0.06% of all manufacturing firms) accounted for 16% of employment in manufacturing (data from Hannah & Bennett, 2022: 835, Table 1).

By 1856 the legal basis for the institution of joint stock and limited liability companies in manufacturing was established. Together with the rise of the London Stock Exchange (LSE),[86] these conditions backed the emergence of the corporation as the basic business unit. Within the manufacturing sector, it was mainly in iron coal and steel, shipping, and cotton that the corporate form was initially adopted (Jeffreys, 1977; Payne, 1967). And, though some lamented the alleged reluctance of British owners in the manufacturing industries to secede their power,[87] the shift toward what Veblen (1924) termed absentee ownership and the rise of what Hannah (1983) termed the corporate economy, took place.

Corporatization also involved the larger use of “credit"[88] as a form of ownership, i.e., as a claim on a future stream of income (Veblen, 1935: 92). These developments played an integral part in altering the “nature of accumulation” and giving rise to *dominant capital* (Bichler & Nitzan, 2004: 287-8). The results presented in Section 4.3 shed light on the role of *energy-core industries* and the transition to fossil-fuels in the transformation of power accumulation regimes. Yet before I proceed, I will present another indicator of change in the business structure of British industry.

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[86] By 1850, the LSE was the largest of its kind, globally, and it retained its dominant position until the outbreak of the first world war (Michie, 1999).

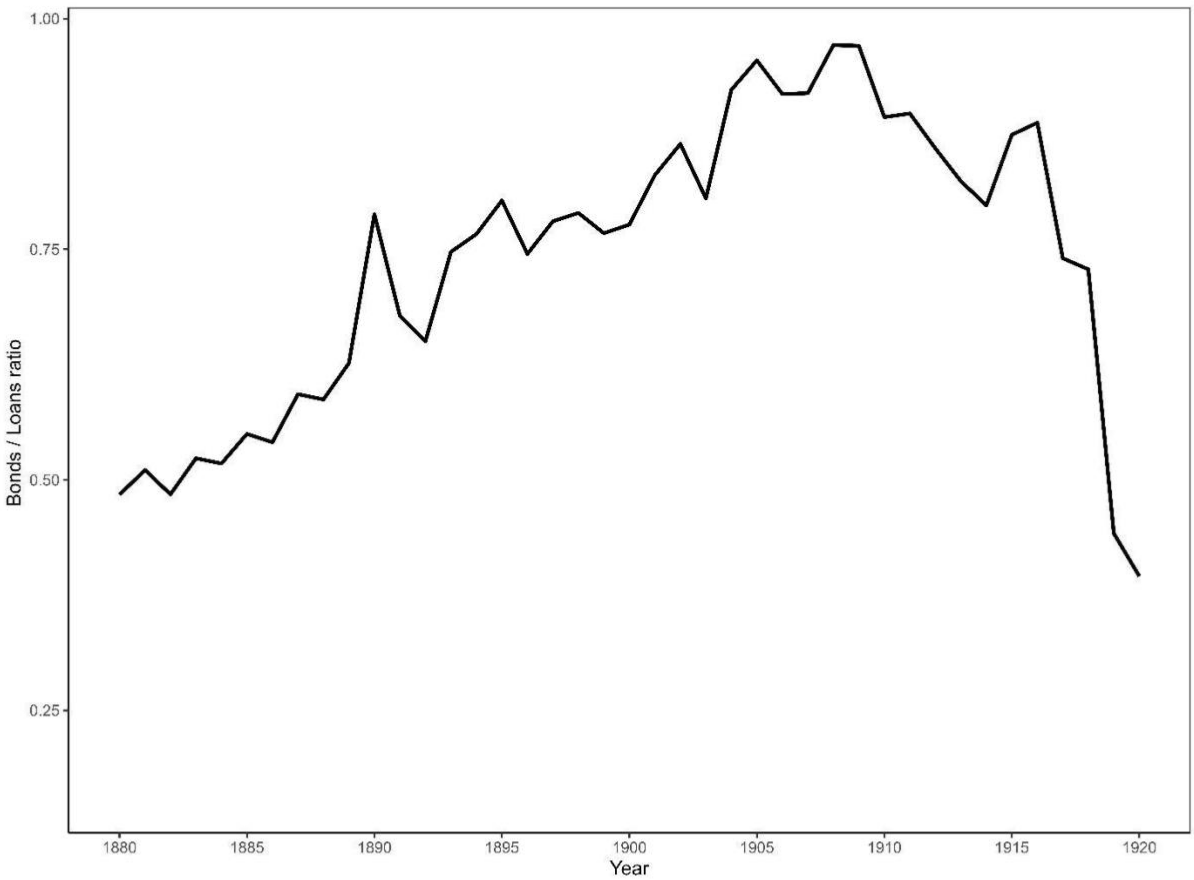
[87] This reluctance resulted in the proliferation of private, rather than public, limited liability companies, and the relatively slow emergence of a professional managerial class (Payne, 1967).

[88] Veblen uses the term *credit* broadly, referring to a wide range of financial instruments which formulate ownership claims over future income, including “loans or debts - notes, stock shares, interest-bearing securities, deposits, call loans, etc.,” (Veblen, 1935: 92). In this analysis I differentiate between bank loans, bonds, and shares, for reasons elaborated upon in the main body of the text.

Figure 9 presents the ratio of total bond par value on the UK's stock exchanges to total loans and advances recorded as assets in all UK banks (see Appendix 4.2). The figure shows the development of the reliance of businesses on stock-market based financing rather than bank loans. Rising from 0.5 in 1880 to almost 1 (0.97) in 1907, the measure indicates that businesses increasingly relied on market-based debt instruments to finance expanding breadth (whether external or internal). This means that British industrial corporations' ability to independently raise funds was growing, and their dependence on banks, a rival ownership group, declined. These findings demonstrate another aspect of the consolidation of dominant capital, its advantaged position, and the role of capitalization in this process.[89]

[89] During WWI, and in the early postwar years in particular, the ratio declined. The source of this reversal is a dramatic rise in the value of total loans and advances, which doubled between the years 1918-1920, while the total bond par value stagnated. A possible explanation for this lies in the lower interest rates on government securities in relation to commercial loans during the post WWI years (Higgins, 1949). This spread between rates on government securities vs. commercial loans might have driven financial institutions to direct liquidity from the former to the latter. Higgins (1949: 19) indicates that competition for commercial paper increased during the immediate post-WWI years. In contrast, it seems that during these years debt-financing through market instruments was harder to achieve. Indeed, during the 1930's bank loans and advances to industry declined once more, and there was a greater industrial reliance on self-finance (Higgins, 1949), so that the ratio of total bond par value to total loans and advances rises once more.

Figure 9: Ratio of Total bond par value to total loans and advances, Britain, 1880-1920



Source: Corporate bond par value from Coyle & Turner, 2013: Appendix, Table 1b. Loans and advances of UK banks: Sheppard, 1971: Tables A1.1-A1.6. UK Bank Balance Sheets 1880-1966.

To conclude, during the turn of the 20th century the British industrial sector underwent a general process of corporatization, and a shift towards the larger use of credit. However, this process was also differential, entailing centralization, the rise of big business, and the consolidation of dominant capital, and, I argue, was tied up with the energy transition to fossil-fuels. As I will show in the following section, tracing the relations between the changing conditions of energy capture and evolving differential accumulation regimes during the transition to steam in the UK, leads to studying the differential performance of the *energy-core* industries.

4.3 The seven good years: the differential rise of the energy-core at the turn of the 20th century

In this section I will present and discuss the results which support the claim that the energy-core was at the heart of early differential accumulation processes, and that business control of these radically changing industries gave rise to the differential accumulation regimes which characterised the capitalist mode of power thenceforth. In the analytical perspective presented in Section 3.5, this process is represented as sociotechnical transformation which is suggested to correspond to change in the breadth and depth of societal energy capture, and internal depth and external breadth strategies of power accumulation. As the 19th century drew to an end, the energy-core experienced a period of “seven good years” (1894-1900) during which they achieved differential accumulation, stabilizing on a new and higher level of relative profit after 1900. The following sections present the results which first drew our attention to the energy-core’s differential rise.

4.3.1 Introducing the energy-core

By the second half of the 19th century, mechanization and the transition to steam occurred across the British manufacturing sector as a whole. Nevertheless, this process was itself differential, both with regard to the quantities of energy and other natural resources required in the manufacturing process, and with regard to the intensity and temporal course of the diffusion of steam power technologies within specific industries.

The industries belonging to what I term the *energy-core*, are at the heart of the energy transition to steam in British industry in that they are either fossil-fuels primary energy resource providers, or industries in which manufacturing processes involve inherently high energy demands. Hence, these industries either enabled the transition to fossil-fuels or were enabled by it. The category includes the mining and quarrying sector, ferrous metals manufacturing, and engineering commodities manufacturing.[90] During the 19th century ferrous metals manufacturing was revolutionized by the introduction of coal, and later coke as fuels, and by developments in furnace techniques, which enabled a shift to high-volume, inexpensive iron and steel production (Brikett, 1922; Smil, 2005). The ferrous metals manufacturing industry not only required great amounts of energy in mining, smelting, and forging, it also supported the flourishing of numerous other energy-intensive industries, such as construction (including infrastructure, urbanization, and energy-intensive building materials such as cement), transportation (including railways, shipping, automobiles, and later aviation), and engineering commodities (including engines, machinery, electrical appliances etc.) (Smil, 2017).

Table 17 presents differential developments in industrial power deployment. As can be seen in this table, the energy-core industries, and the textiles, leather and clothing industries have the highest absolute quantities and shares of installed power capacity. Yet, between these energy intensive industries, the differential geometric annual growth rate of installed capacity in the energy-core industries is the highest (4.3%, in comparison to 2.8% in textiles. leather and clothing). Installed capacity in metal manufacturing rose by a factor of 5.6, from 450 thousand hp in 1870 to over 2.5 million hp in 1907. By the latter year, it surpassed both mining and quarrying and textiles, leather, and clothing in its share of mining and manufacturing installed capacity which reached 31.3%. The share of installed capacity in textiles, leather, and clothing, which in 1870 was the highest share (36.8%), was reduced to 26.7% in 1907.

[90] Ferrous metals manufacturing involves the initial manufacturing of pig iron from iron ore, and its later use in the manufacturing of iron alloys such as steel and wrought iron. In the term *engineering commodities*, I refer to the production of engines, machinery, tools, and equipment, and engineering services, as defined by the 1911 UK Census of Production.

Table 17: Installed power capacity measures, by industry, Britain, 1870-1907

Industry	***Installed power capacity (000's HP), 1870***	***Installed power capacity (000's HP), 1907***	***Share in total mining and manufacturing installed power capacity (%), 1870***	***Share in total mining and manufacturing installed power capacity (%), 1907***	***Compound annual growth rate (%), 1870-1907***
Energy-Core	*1,050*	*5,006*	*50.6*	*62.8*	*4.3*
Mines	*600*	*2,495*	*28.9*	*31.3*	*3.9*
Metal manufacturing	*450*	*2,511*	*21.7*	*31.5*	*4.7*
Textiles and Clothing	*760*	*2,128*	*36.8*	*26.7*	*2.8*
Other manufacturing	*262*	*842*	*12.6*	*10.5*	*3.2*

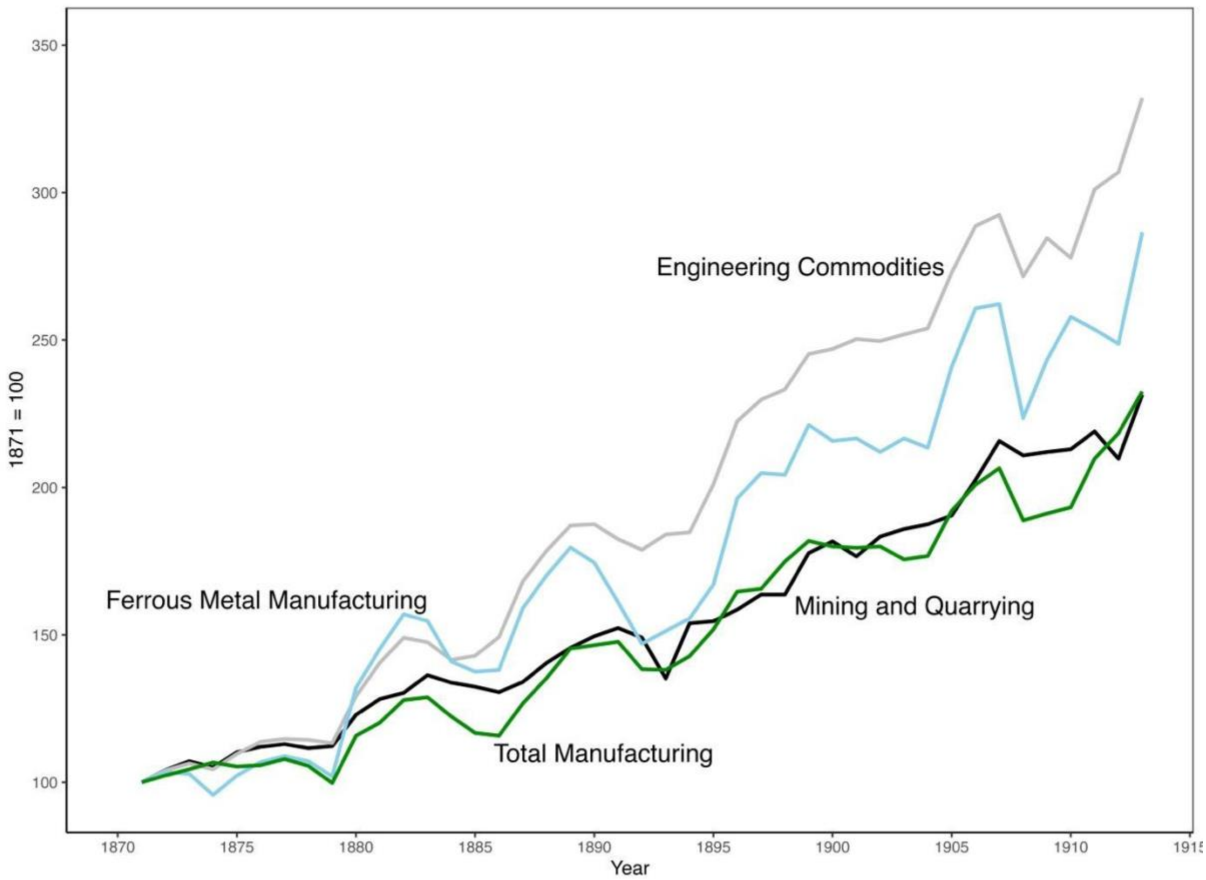
Source: Kanefsky, 1979: 344, Table 7.15.

I turned to differential national accounts measures to study the differential performance of the energy-core. Looking differentially at the growth rates of Gross Value Added (GVA)[91] by industry between 1855-1913 shows us that the GVA levels of *energy-core* industries surpassed most other industries, with two interesting exceptions, as will be described forthwith.

Figure 10 - Figure 12 show GVA levels by industry by normalizing industrial GVA so that 1871 = 100. The results plotted in Figure 10 focus on the energy-core industries (plotted in light blue, grey, and black) relative to the total manufacturing GVA levels (plotted in green henceforth). The mining and quarrying sector exhibits a trend similar to that of total manufacturing in GVA levels, which both rose to 1913 = 233. Ferrous metals manufacturing and engineering commodities surpassed these, beginning to differentially rise in 1880 so that 1913 = 319, and 1913 = 332, respectively.

[91] Gross Value Added is a pecuniary measure of the "value" of goods and services produced by or in a defined unit (e.g., area, industry, sector of the economy), over and above the cost of its inputs. For further details see Appendix 4.2.

Figure 10: GVA by industry, Britain, 1871-1913 – Energy-core industries

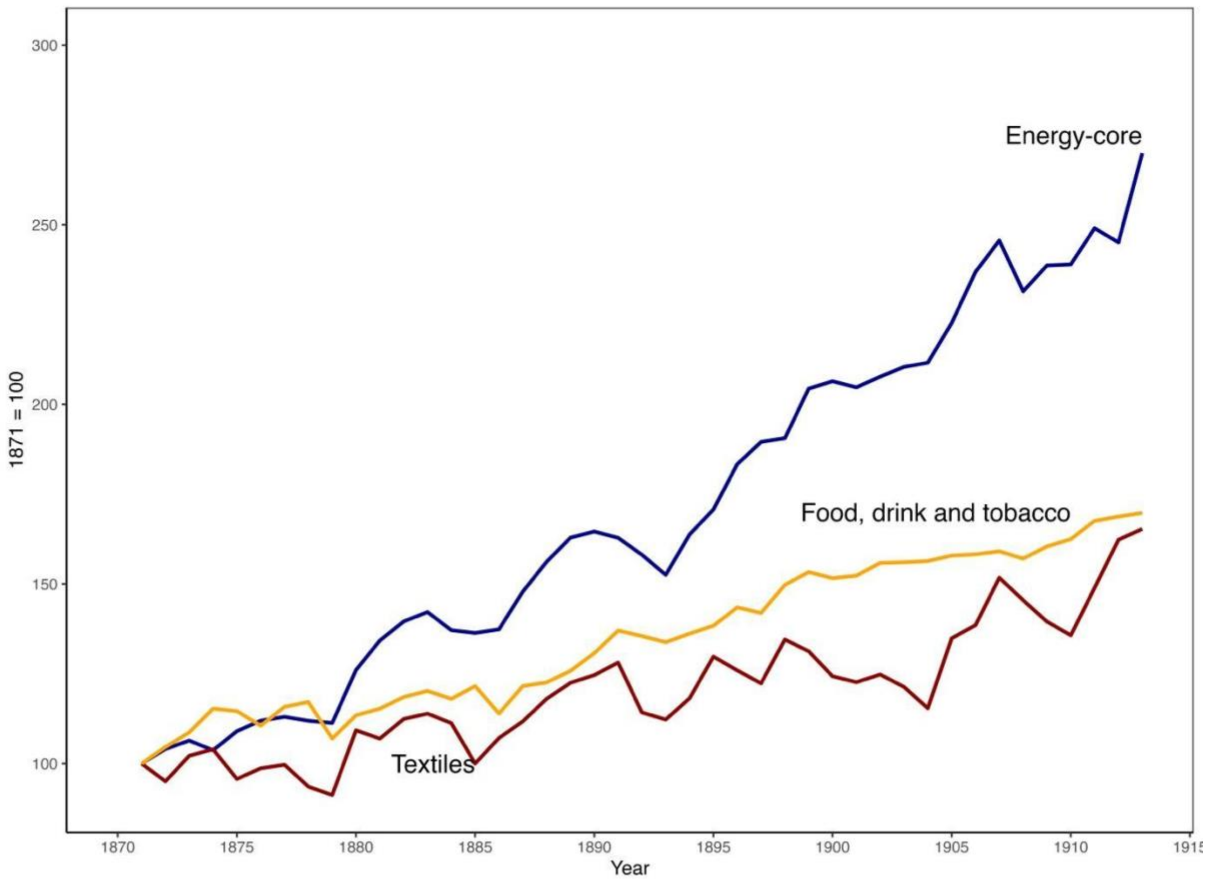


Source: GVA by sector at 1907 constant price from: Lewis, 1967: 118, Appendix III, Table 14: Gross Domestic Product at 1907 constant prices. GVA by industry in 1907 constant price calculated using: Lewis, 1967: 86, Appendix I, Table 5: Weights used for industrial production, Base 1907, and Feinstein, 1972: T111, Table 51: Index of Industrial Production by Main Orders, 1855-1965. Engineering Commodities GVA in 1907 constant prices was calculated using: Census of Population, England and Wales, 1911, General report with appendices: Appendix C, Table 64: Occupations of Males and Females, p. 264-5. Definition of engineering commodities category is from: Census of Production, 1907, Preliminary Tables, part II: 7. Engineering Factories (including Electrical Engineering), Table I: Output, p. 28-9, Lewis, 1967: 86, Appendix I, Table 5: Weights used for industrial production, Base 1907: "Ferrous Metals Products", and Feinstein, 1972: T111, Table 51: Index of Industrial Production by Main Orders, 1855-1965: "Engineering".

Note: Energy-core industries' GVAs are highly correlated between themselves. The Pearson correlation coefficient for ferrous metals manufacturing GVA and engineering commodities GVA is r = 0.99. The Pearson correlation coefficient for ferrous metals manufacturing GVA and mining and quarrying GVA is r = 0.98.

Figure 11 shows that the growth rates of energy-core GVA levels (plotted in blue henceforth, 1913 = 270) significantly out-performed those of the consumer products industries of food, drink, and tobacco (plotted in orange henceforth), as well as textiles, leather, and clothing (plotted in red henceforth), whose levels rose to 1913 = 170, and 1913 = 169 respectively.

Figure 11: GVA by industry, Britain, 1871-1913 – Energy-Core Industries, Textiles, Leather and Clothing, and Food, Drink and Tobacco



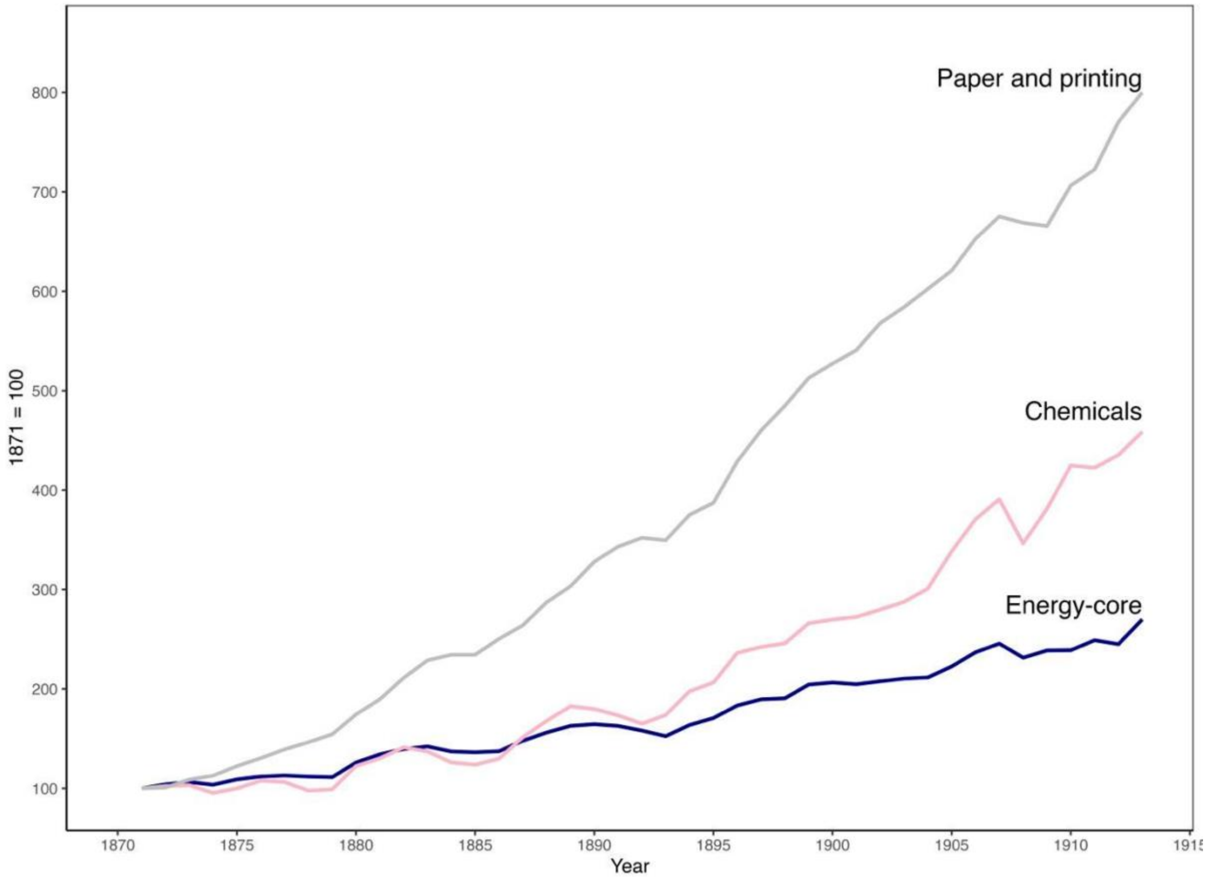
Source: see Figure 10.

As presented in Figure 12, the only industries whose rise in GVA levels rivalled and exceeded those of the energy-core industries were two upcoming and themselves energy-intensive industries – chemicals, and paper, printing, and publishing.[92] Yet though the rise in GVA levels of these two industries is differentially rapid, in absolute GVA terms, these industries were

[92] Smil calculates that the energy intensity of paper lies between 23-35 MJ/kg, higher than steel from pig iron (20-25 MJ/kg) (Smil, 2017: 16).

both still small at the turn of the 20th century.[93] Their period of differential accumulation began as the 20th century dawned, when the energy-core industries had already established their dominant position.[94]

Figure 12: GVA by industry, Britain, 1871-1913 – Energy-Core Industries, Paper and Printing, and Chemicals



Source: see Figure 10.

[93] Chemicals GVA grew from 5.3 million to 24.5 million 1907 constant pounds between 1871-1913, and paper and printing GVA grew from 5.5 to 43.8 million 1907 constant pounds. During the same period, engineering commodities' GVA grew from 33.5 million to 111.4 million 1907 constant pounds. Thus, in the case of chemicals, engineering commodities' GVA was greater by a factor of 6.3 in the beginning of the period and by a factor of 4.5 at its end, while in the case of paper and printing by a factor of 6 at the start and only by a factor of 2.5 at the end. Being an enlightened capitalist seems to have paid off.

[94] Note that these trends occurred during the so-called long depression (1879-1896) or climacteric of British industrial growth (1873-1913) (Lewis, 1967; Musson, 1959). As can be seen in the graphs, and as has been noted in the literature (Capie & Wood, 2013), this alleged recession was one of prices rather than production. Prices fell, and there were much talk and complaints about depressed production, but this is not evident in output nor employment data for the time (Capie & Wood, 2013; Musson, 1959).

4.3.2 Tracing the energy-core's seven good years

Next, I turned to measures of differential capital accumulation, to assess whether the differential growth in industrial energy consumption was coupled with energy-core industries attaining a dominant business position. An analysis of the strategies behind the consolidation of the energy-core industries' dominant position will enable us to explore the relations of energy capture, differential accumulation regimes, and socio-technical change suggested in Hypothesis 1.

The results revealed that between 1894-1900 the energy-core experienced seven years of rapid differential accumulation which resulted in the stabilization of their relative profit on a new and higher level. These seven good years followed a period in which it seems that no group within the British industrial sector succeeded in attaining *stable* differential accumulation. Rather, ownership groups appear to have jointly ridden the waves of fluctuating prices, while falling prices offset potential differential gains. Before presenting the results, which point to the possible mechanism behind the energy-core's differential rise, I will present the results which uncovered the seven-year differential accumulation process itself.

Figure 13 and Figure 14 present a broad measure of estimated business income[95] by industry, calculated by deducting estimated labour income by industry[96] from GVA by industry. These measures give us an initial indication of the differential performance of energy-core businesses in relation to total manufacturing and textiles manufacturing, which was another of the major industries in Britain at the time, as well as a harbinger of mechanization and the transition to steam in British industry.

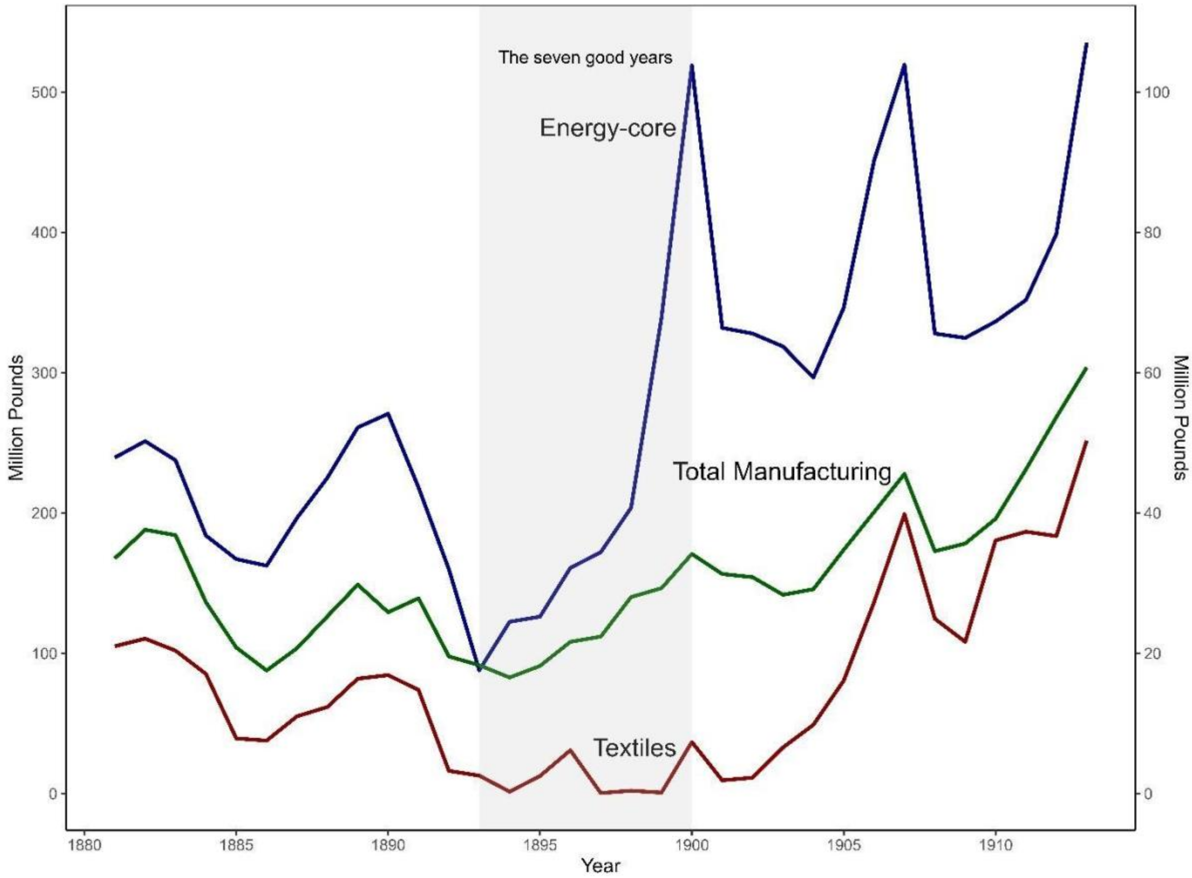
[95] Business income by industry is a measure of the total value appropriated by employers and the self-employed in each industry. For further details see Appendix 4.2.

[96] Labour income by industry is a measure of the total value of all forms of employment-based income (e.g., wages and salaries) in each industry. For further details see Appendix 4.2.

Figure 13 presents business income by industry between 1881-1913,[97] in absolute nominal terms. Like the trend in total manufacturing, and in contrast to textiles, whose business income began to rise only after the turn of the 20th century, energy-core industries' business income begins to rise in 1894, rising in half a decade by a factor of 4.2, from 24.5 million pounds in 1894 to 103.8 million pounds in 1900. Total manufacturing business income rose as well, but not as steeply, by a factor of 1.9, from 91 million pounds in 1895 (when manufacturing business income began to rise) to 170.8 million pounds in 1900. The volatility displayed by energy-core business income after 1900 is mainly due to the mining and quarrying sector (as will be elaborated upon in the discussion of Figure 14), yet the general trend is that of growth, reaching 107 million pounds in 1913. The figure suggests that, starting in 1894, the energy-core industries began to appropriate differentially higher business income, in relation to both total manufacturing and the textiles manufacturing industry.

[97] Business income measures go back to 1881 due to data limitations, i.e. Feinstein's (1990) average annual wage estimations for which 1881 is the starting point.

Figure 13: Business income by industry, UK, major industries, 1881-1913



Note: Total manufacturing business income is plotted against the left Y axis, energy-core and textiles business income are plotted against the right Y axis.

Source: GVA by industry: see Figure 10. Average annual earnings per worker and number of workers by sector and industry: calculated from Feinstein, 1990: 604, 608-611 Table 3: Manufacturing: number of wage-earners, United Kingdom, 1881 and 1911 and average annual full-employment earnings, 1911, Table 4: Indices of average full-time money earnings by sector, 1880-1913 (1911 = 100), and Table 5: Indices of average full-time earnings, manufacturing, 1880-1913 (1911 = 100). Engineering commodities: see Figure 10.

Figure 14 displays the disaggregated business income of energy-core industries. As can be seen, all three energy-core industries follow a similar general trajectory. Nevertheless, mining and quarrying (plotted in black henceforth) displays high volatility, while both ferrous metals manufacturing (plotted in light blue henceforth) and engineering commodities (plotted in grey henceforth) display sustained growth trends, with each local minimal point higher than the preceding minimal point.

The engineering commodities industry in particular displays the highest business income in absolute terms between 1893-1913 (save for two years in which it is surpassed by mining and quarrying).[98] It also displays the highest average annual business income throughout the period (26.4 million pounds), and a clear growth trend in which every local maximal point is higher than the one preceding it. As in the GVA levels presented in Figure 10, throughout the thirty-years period between 1881-1913, the engineering commodities industry's business income growth outstripped that of other energy-core industries, as well as that of total manufacture and other core industries of British manufacturing at the time.

Moreover, the significant period of growth in absolute business income, for both ferrous metals manufacturing and engineering commodities manufacturing, occurred between the years 1895-1900. In addition, note that during these years there is a divergence within the energy-core, the mining quarrying sector suffers differential losses and only begins to regain a slightly higher average business income level after 1900. This finding will be elaborated upon further on.

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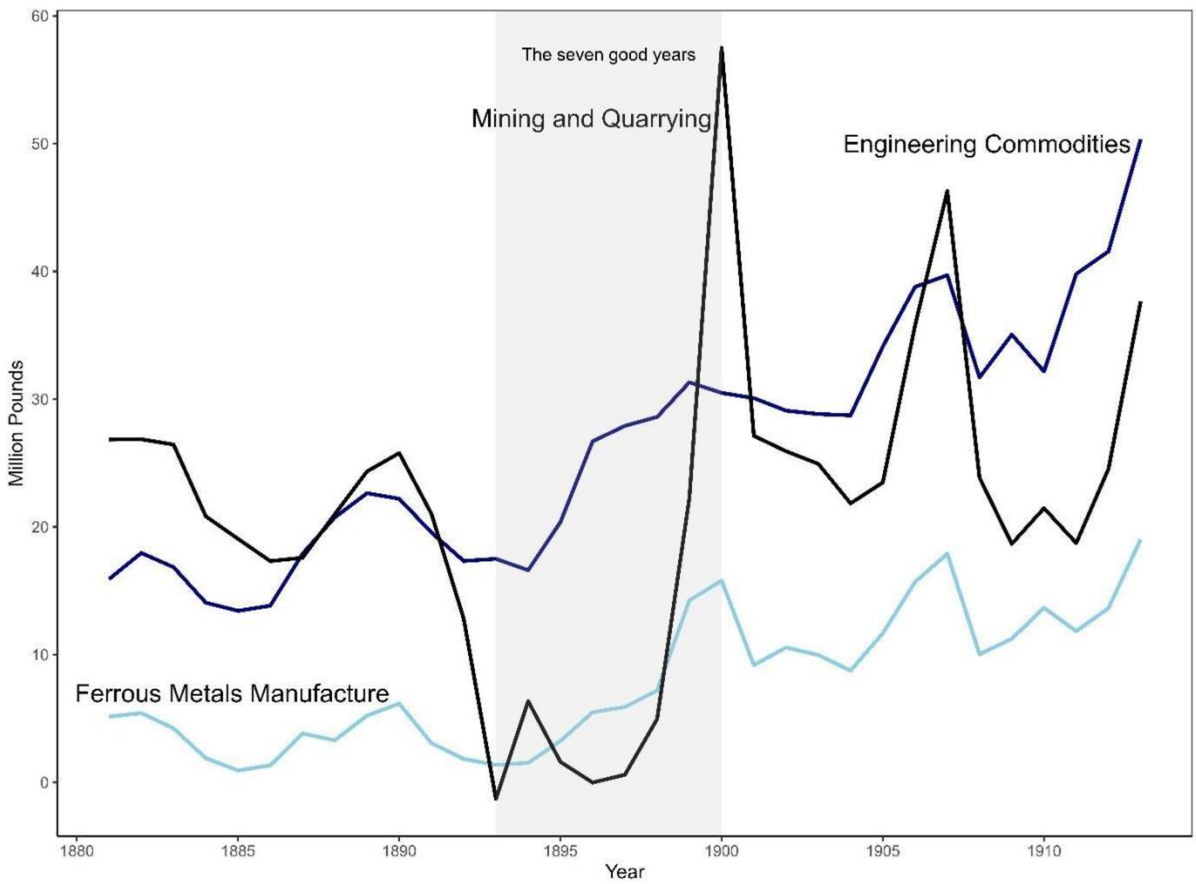
[98] It is important to note that the figures presented in this analysis are estimations, and themselves based on estimated figures (i.e., estimated numbers of employees, average annual wages, GVA, and price indices, by industry). It cannot be claimed with any certainty that the estimations represent actual historical figures, in absolute terms. For instance, it is doubtful that mining and quarrying business income was negative in 1893. As in other cases, the numbers may be skewed due to inaccuracies in the estimations of the components of the business income formula. Nevertheless, it is assumed that while the absolute figures may be inaccurate, the trends which they represent correspond to actual historical trends. For this reason, among others, I will focus on differential analysis, for which *relative trajectories* are of greater significance than *absolute quantities*.

Figure 14: Business income by industry, UK, energy-core industries, 1881-1913



Source: see Figure 13.

Note: Energy-core industries' business incomes are highly correlated between themselves. The Pearson correlation coefficient for ferrous metals manufacturing business income, and engineering commodities business income is r = 0.92. The Pearson correlation coefficient for ferrous metals manufacturing business income and mining and quarrying business income is r = 0.65.

Figure 15 and Figure 16 depict differential measures of business and corporate income.[99] Corporate income is calculated as the product of estimated business income and the share of trading profits in non-farm income, so as to obtain the share of business income which is appropriated by firms, without self-employed income.[100] The differential measures are calculated by dividing the business and the corporate income of a certain industry or group of

[99] Corporate income by industry is a measure of the total value appropriated by employers in each industry. It is the total business income after deducting the income of the self-employed. For further details see Appendix 4.2.
[100] Trading profits is another term for operating income, i.e., what remains of a company's revenue after deducting the costs associated with producing and selling its goods, and other operating expenses. Non-farm income refers to income from all sectors of the economy save for agriculture. For further details see Appendix 4.2.

industries by the total mining and manufacturing business income (for further details and explanations see Appendix 4.2). These measures of differential profit reveal more clearly the energy-core's seven good years, the rapid rise in the energy-core's differential profit between the years 1894-1900.

As presented in Figure 15, while the ratio of textiles manufacturing business income to total mining and quarrying business income declined during the late 19th century (1881-1900), that of the energy-core industries, albeit volatile, rose significantly, especially during the seven good year period, 1894-1900. The energy-core industries' differential business income almost doubled, rising by a factor of 1.8 between 1881, when its share of mining and manufacturing business income was 25%, and 1900, when its share reached 45%. In 1900 the textile manufacturing industries' share of mining and manufacturing business income was a mere 3%. Yet more significantly, it seems that during the very end of a period of global economic recession, the so-called *long depression* (1873-1896), which allegedly hit British industry most severely (Musson, 1959), energy-core businesses proceeded to appropriate rising shares of mining and manufacturing business income. During the crucial period of consolidation of dominant capital in the UK, energy-core industries led differential accumulation processes which matured during the waning of an alleged recession (the so-called *climacteric* in British industry, see Section 3.7.1.2), when falling prices caused much anxiety and fret among British industrialists (Musson, 1959). This crisis, it appears, was one of business profits rather than production.

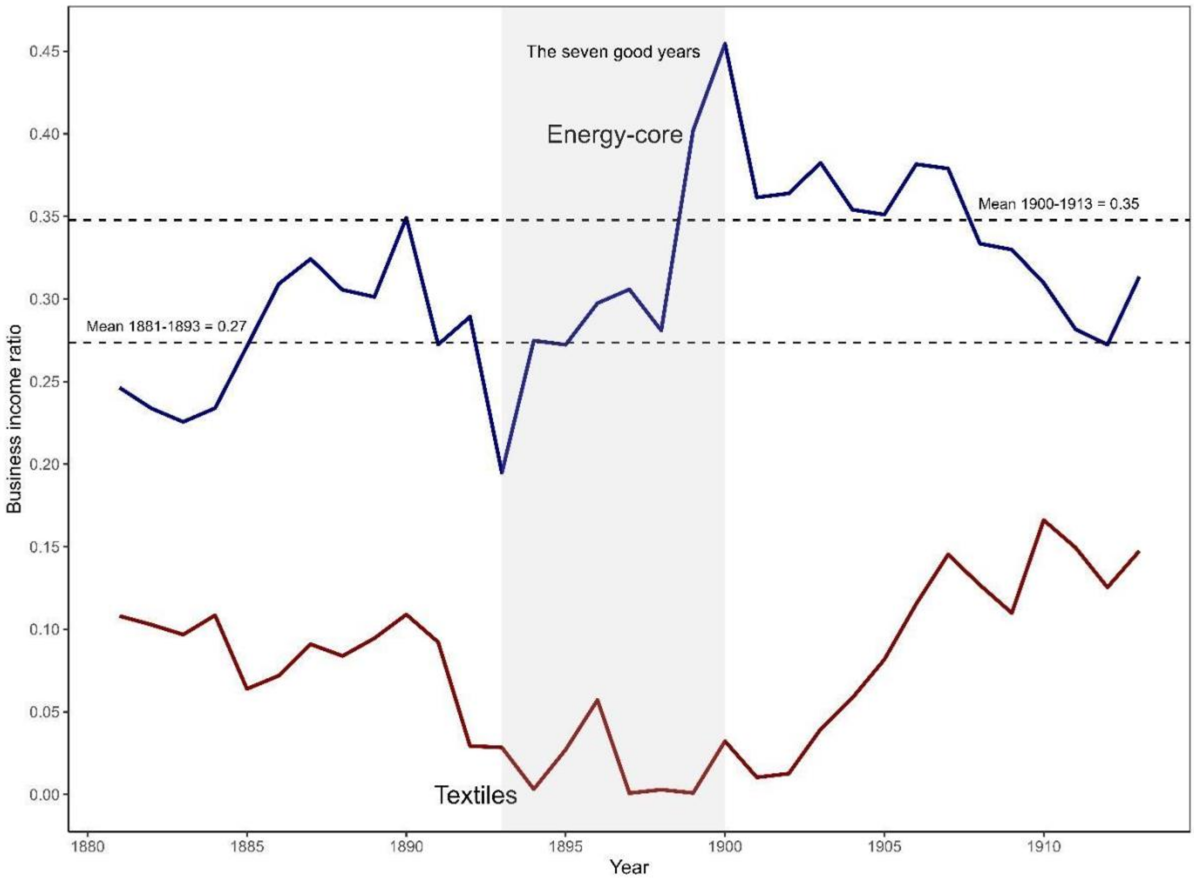
Moreover, up until the mid-1890's seven good years, the differential business income of textiles and the energy-core moved together, riding the waves of price fluctuations. However, in 1894 the trends diverged and the differential business income of textiles and of the energy-core began to move *inversely*. Hence, while throughout the 1880's and early 1890's business income in both the textiles and energy-core industries may well have suffered from falling prices during the 1890's, during the energy-core's seven good years (1894-1900) energy-core industries' business income seemed to differentially gain. In the following section, I will present the results which pointed towards the cause of this divergence, and the potential differential pricing mechanism at the base of the energy-core's seven good years.

After a period of rapid rise in differential business income between the years 1894-1900, energy-core's differential business income stabilized between the years 1900-1913 on a level averagely 8% higher that of the years 1881-1893 (0.35 and 0.27, respectively).

The trend is apparent also when considering the ratio of industrial-specific corporate income to mining and manufacturing business income. Figure 16 shows that energy-core industries firms' share of mining and manufacturing business income rose by a factor of 2.5 between 1881-1900 (7.6 and 18.5, respectively) while that of the textiles manufacturing industries declined from 3.3% to 1.3%. After 1900 the textile manufacturing industries began to recover, and energy-core industries' differential business and corporate income level off, yet on a new and higher level.

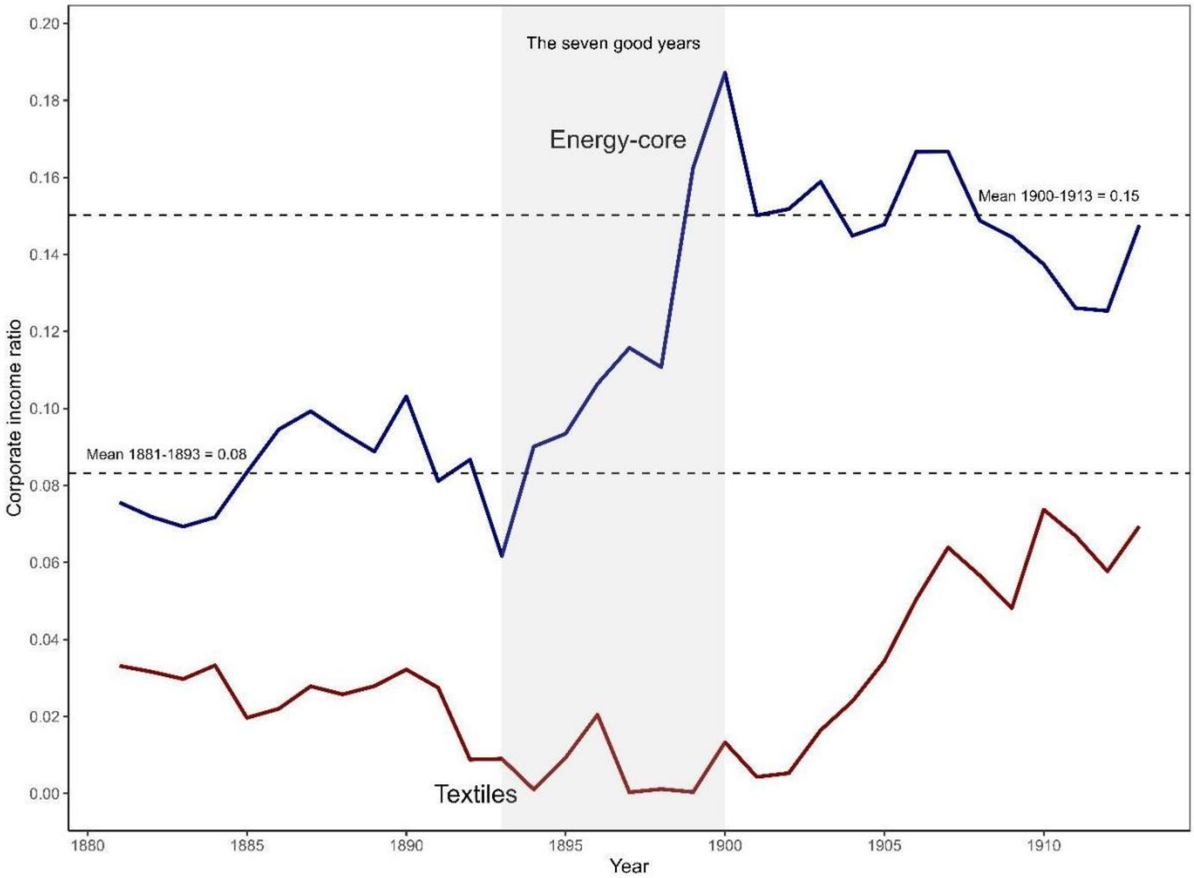
The average level of energy-core differential corporate income in the period 1900-1913 was almost double the level between 1881-1893 (0.15 and 0.08, respectively). Note that, once again, while up until 1893 the textiles and the energy-core's differential business income moved in tandem, in 1894 they diverge and the period between 1894-1900 is the period in which the energy-core's differential corporate income rises to a higher level.

Figure 15: Differential business income - Industry-specific business income to total mining and manufacturing business income ratio, Britain, 1881-1913



Source: see Figure 13.

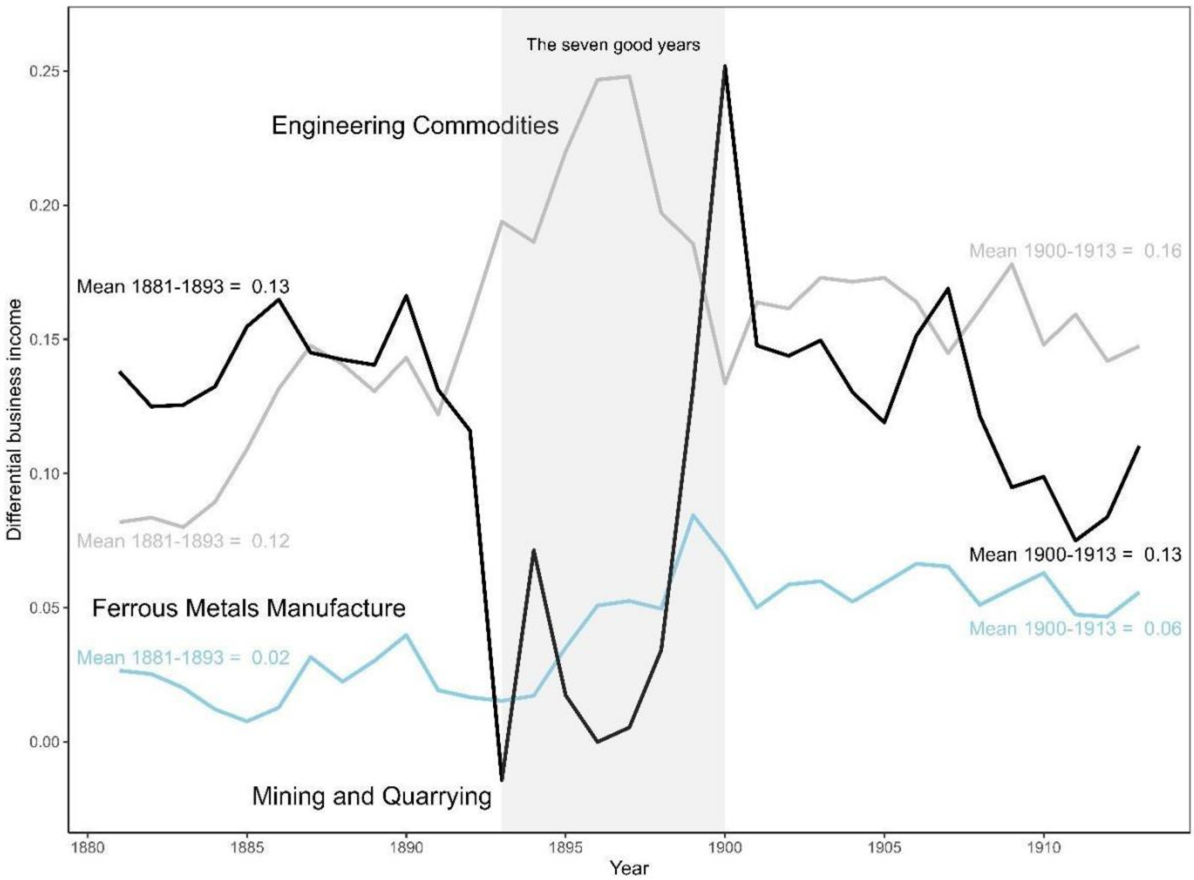
Figure 16: Differential corporate income - Industry-specific business income to total mining and manufacturing business income ratio, Britain, 1881-1913



Source: Business income by industry: see Figure 13. Share of trading profit in non-farm income: calculated from Solomou & Thomas, 2019: 49-50, Table A5: Breakdown of Gross Trading Profits and Self Employment income.

And what of the differential business income of the industries which make up the energy-core? Figure 17 presents a break-up of the energy-core's differential business income, revealing an inner differentiation between them. The differential business income of ferrous metals manufacturing rose steadily throughout the seven good years and stabilized between 1900-1913 on an average differential profit level three times higher than its corresponding average level between 1881-1893 (0.06 and 0.02, respectively). Meanwhile, engineering commodities' differential business income rose and fell over the period of the seven good years and stabilized on an average differential profit level 1.2 times higher than its corresponding average level between 1881-1893 (0.16 and 0.13, respectively). The mining and quarrying sector, on the other hand, suffered a differential decline between 1894-1897 and does not enjoy the differential leverage of the seven good years.[101]

Figure 17: Differential business income – energy-core industries business income to total mining and manufacturing business income ratio, Britain, 1881-1913



Source: see Figure 13.

In the following section (Section 4.3.3), I will discuss the significance and possible causes of this differential performance, but first I will turn to the analysis results which give us an

[101] It should be pointed out at this stage that the measures presented above are more accurately described as concentration rather than differential measures. They suffer an aggregation restriction which denies us the ability to study relations between typical business units. This is due to a lack of reliable and comprehensive data on the number of firms by industry. For example, this means that instead of studying the relation between the business income of a typical (average) ferrous metals manufacturing firm and a *typical* mining and manufacturing firm, or a *typical* engineering commodities firm, we are studying the relation between the aggregates of these groups. From studying aggregates we know little of the differential power of firms, as this might change as the internal constitution of an industrial sector changes (i.e., the number of firms and their concentration). For instance, while ferrous metals manufacturing displays a rapid rate of growth in differential business income when compared to engineering commodities, its levels of differential business income are significantly lower. In order to compare these two industries, we need a measure of average income per firm, which we are lacking due to data limitations. For a further discussion of this point see Bichler & Nitzan (2021).

indication of the differential performance of dominant energy-core firms (see Appendix 4.2). The following figures present differential accumulation measures in which the differential value of energy-core firms' securities and the differential yield on these securities are used as a proxy for the dominant energy-core firms.[102] The measures are used to further explore the consolidation of an energy-core-based dominant capital formation. They will be complemented by an analysis of the business pathways on which this differential rise was based.

Table 18 shows the differential total capitalization[103] of energy-core firms' securities.[104] It represents the share of the total nominal value of energy-core firms' securities in the total nominal value of securities listed on the London Stock Exchange (LSE). It is thus assumed that a rise in the share of energy-core firms' total capitalization in the total capitalization of securities indicates that these industries are beating the general growth rate of capital on the LSE (see Appendix 4.2). In this sense, the measure further demonstrates the differential rise and dominance gained by energy-core businesses during the turn of the 20th century, which between 1900 and the onset of WWI stabilized on a new and higher level of differential accumulation.

As the results presented in Table 18 show, the most significant growth in the share of energy-core total capitalization in total LSE capitalization occurred between 1893-1903 (from 1.5% in 1883 to 6.1% in 1903), a period corresponding to the energy-core's seven good years of differential business and corporate income presented in Figure 15 and Figure 16. This growing share in total capitalization is an additional indication of the energy-core's differential rise

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[102] This measure is based on the assumption that the firms listed on the LSE represent the bigger and dominant firms in each industry.

[103] Total capitalization refers to the total value of long-term debt and equity (e.g., bonds and shares) which comprise a firm's capital structure.

[104] Due to data restrictions, the *energy-core industries* category consists of a slightly different composition. The engineering commodities manufacturing industries are not represented, and three main industries make up the category: coal, iron, and steel (representing coal mining and ferrous metal manufacturing), gas, and shipping for the period of 1883-1913, adding the new industries of oil, nitrates, and electricity as they appeared in 1913. The addition of new industries is mentioned in the data and figures.

during the turn of the 20th century, as it beat the market's average total capitalization growth rate. In contrast, the share of railway firms, which are considered the driving force behind the development of British stock markets during the 19th century (Mitchell, 1964), in total LSE capitalization declined during the turn of the 20th century, their growth rates falling below the general market rate of growth as investors turned to industrial, commercial and mining securities (Michie, 1999).

Table 18: Share of energy-core industries' total capitalization in total LSE capitalization (%), 1873-1913

Year	***Iron, coal, and steel***	***Energy-core***	***Energy-core (Including new)***	***Railways***
1873	0.3	1.5	1.5	32
1883	0.4	1.9	1.9	40.6
1893	0.3	1.9	1.9	49.4
1903	4.1	6.1	6.1	44.1
1913	3.5	5.4	6.5	43.4

Source: Share of LSE securities from: Michie, 1999: 89, Table 3.3: Nominal values of securities quoted in the Stock Exchange Official List, 1853-1913 (%).

Due to data restrictions, I cannot present a measure of differential income for big energy-core firms relative to average industrial business income. Nevertheless, in Figure 18 I use energy-core firms' total capitalization as a tentative proxy for the relative magnitude of dominant firms' income (see Appendix 4.2). The figure presents a measure of the differential performance of dominant energy-core firms, relative to that of the total mining and manufacturing sector (including the mining and quarrying sector, and all manufacturing industries, e.g., textile manufacturing, energy-core industries, clothing, food, drink, and tobacco, chemicals, etc.).

Figure 18 presents a tentative proxy measure for dominant energy-core firms' performance (as opposed to *general* energy-core performance). The measure is expressed as the quotient of energy-core firms' total capitalization and mining and manufacturing business income, showing that the former grew steeply in relation to the latter during the turn of the 20th century. The measure is designed to make up for a lack of accounting records data for dominant energy-core firms, yet its results must be interpreted with caution.[105] The limited liability form was applied early and predominantly to energy-intensive industries, and the large firms resulting from the late 19th century M&A waves were listed on the LSE (Cheffins, 2008; Payne, 1965; Shannon, 1933).

Hence, I use the nominal value of energy-intensive industries listed on the LSE as a rough proxy for the trajectory and relative magnitude of dominant energy-core firms' income, assuming that a significant portion of big firms was listed on the LSE, while smaller firms were not. Due to data restrictions, Figure 18A shows a narrow category of the iron, coal, steel and mining industries only as the energy-core, without engineering commodities manufacturing, which amounted to the central energy-core industry in previous analysis. Figure 18B tries to make up for this lack by adding gas, shipping and shipbuilding, telegraph, and trams to the energy-core total capitalization category (as a proxy for engineering commodities, within the restrictions of the categorization of LSE securities data), as well as oil, nitrates and electrical lighting as they appear in 1903-1913.

Nevertheless, the trends still hold, even for the narrow version of energy-core firms. The ratio rose throughout the late 19th century, soaring by a factor of 4.6 in the decade 1893-1903 (from

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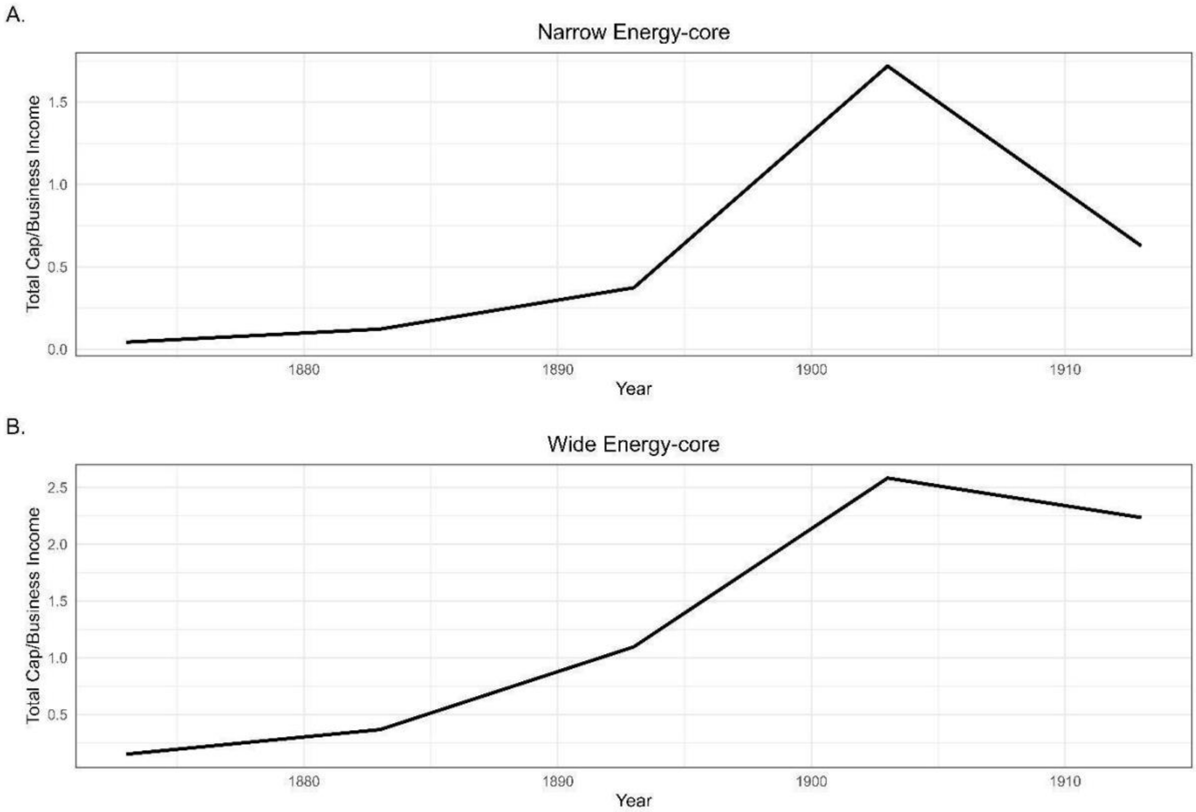
105 The main caveat stems from the division of capitalization by income. While current earnings are a basic component of the capitalization formula, capitalization, as an expression of expected future earnings discounted to current value, is also dependent on the discount rate, hype, and risk perceptions (see Section 2.2.1). Hence, it does not reflect present income as such, but rather the expectations regarding future performance, as well as the discount rate. Nevertheless, current earnings are a major component of future expectations. Thus, while capitalization can give us a certain sense of current business performance, it harbours also future expectations, fears, and hopes, which business income does not.

0.37 to 1.7), after rising by a factor of 3 during the two preceding decades (from a mere 0.04 in 1873). In the case of the wide measure the rise is more evenly distributed: a factor of 2.4 between the years 1873-1883, is followed by a factor of 3 between the years 1883-1893, and finally a factor of 2.4 again between the years 1893-1903.

Figure 18: Energy-core firms' total capitalization / Total mining and manufacturing business income, Britain, 1873 – 1913



Source: Total manufacturing business income: see Figure 13. Nominal value of energy intensive industries' securities: see Table 18. Manufacturing business income for 1873 was estimated by extrapolating average annual earnings in manufacturing.

To conclude, during the seven years between 1894-1900, British energy-core firms beat the average industrial rate of accumulation, achieving an advantaged position in the early consolidation of dominant capital. The following section will present an analysis of the business pathways at the base of this process.

4.3.3 The energy-core's differential accumulation pathways

As the results presented in this section suggest, the two main business pathways which accompanied the rapid transition to fossil fuels during the second half of the 19th century were external breadth (greenfield development and growth in size) and internal depth (specifically, enhanced productivity).[106] However, throughout most of the 19th century, and up until its very final years, these two pathways were difficult to control and leverage in differential accumulation. Indeed, during the 1870's and 1880's, external breadth and internal depth did not result in stable differential accumulation for any capitalist group because potential differential gains were offset by falling output prices (recall the deflationary period of the long depression between 1873-1896). I argue that this state of affairs changed during the 1890's when the energy-core entered its seven good years by leveraging and fulfilling a potential to control differential prices. As I will show, during these years, and in contrast to the earlier period, energy-core differential prices and differential output moved in tandem.

Hypothesis 1 suggests that changes in the breadth and depth of energy capture correspond to both external breadth and internal depth business pathways of differential accumulation. The breadth and depth of differential profit are defined, respectively, as organizational size, i.e., basic quantities controlled by the capitalist entity, and elemental power, i.e., the earnings per basic unit of operation (see Section 2.2.3).

4.3.3.1 Employment-based measures

I first turned to Bichler and Nitzan's (2009) formula of differential profit, which defines *employees* as the basic unit of organization (for further explanations, see Section 2.2.3). Figure 19A presents the employment concentration of textiles and the energy-core, and Figure 19B

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[106] Internal depth (cost-cutting) can take different forms: it may be pursued by enhancing productivity per basic unit of operation, or by lowering input costs in relation to output prices.

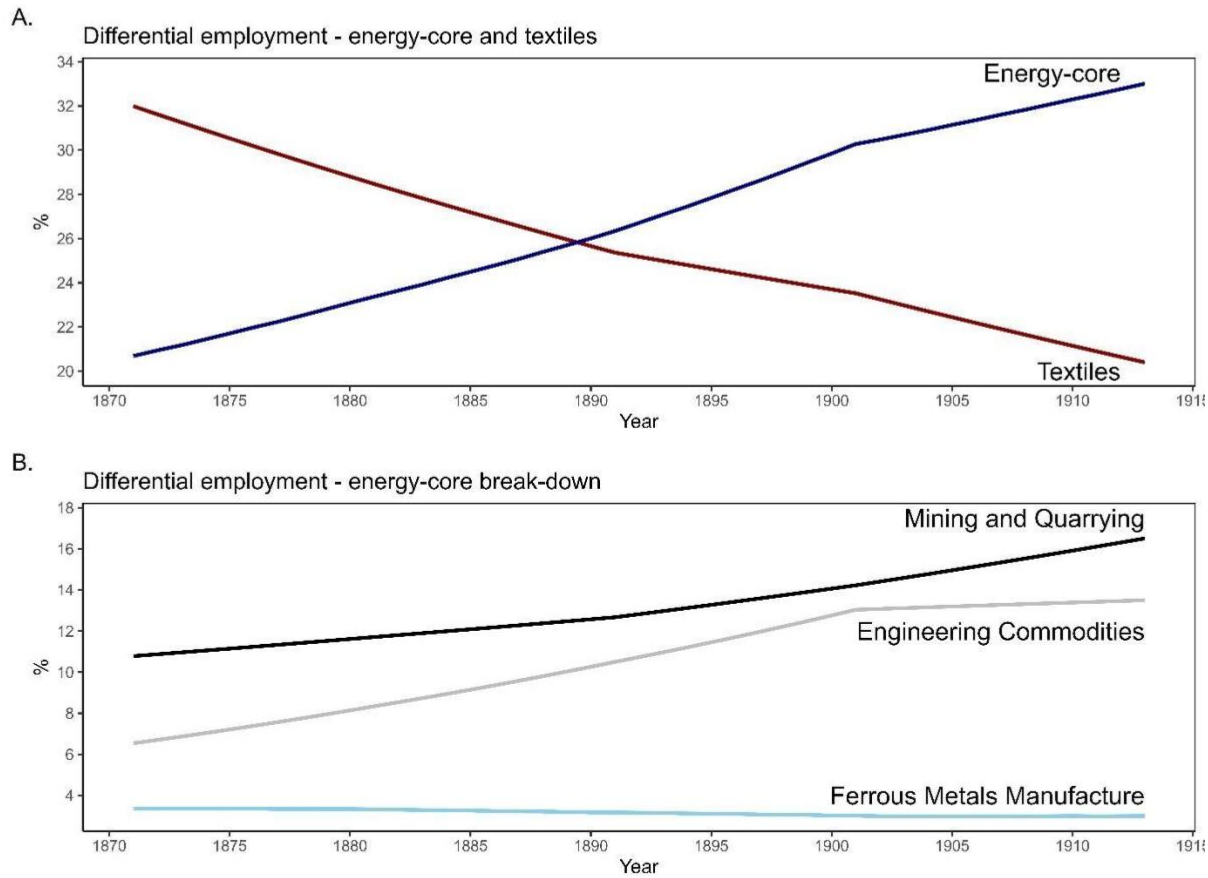
shows the break-down of the energy-core, presenting employment concentration for mining and quarrying, ferrous metals manufacturing, and engineering commodities. It plots the development of these industries' share of employees in total mining and manufacturing employees.

As can be seen in Figure 19A, the share of textile employees in total mining and manufacturing employees and of energy-core employees in total mining and manufacturing employees move inversely between the years 1871-1913. As the share of textiles fell from 32% to 20%, the share of the energy-core rose from 21% to 33%.

Figure 19B shows that within the energy-core there is a significant difference between engineering commodities and the mining and quarrying, for which the share in total mining and manufacturing employment rose between 1871-1913 (from 6.5% to 13.5%, from 10.8% to 16.5%, respectively) and ferrous metals manufacturing, for which the share in total mining and manufacturing employment declined slightly (from 3.4% to 3%).

These results suggest that while the energy-core engaged in differential breadth pathways, expanding in size (i.e., the control of basic units of operation – employees), these efforts were led by the engineering commodities sector, while the ferrous metals manufacturing sector did not embark on this pathway, implying that the source of its differential accumulation during the energy-core's seven good years lay elsewhere.

Figure 19: Differential breadth pathways – differential employment, Britain, 1871 – 1913



Source: See Figure 13.

Arguably, and as suggested in hypothesis 1, the differential breadth processes depicted in Figure 19 can be identified as predominantly external. The Buy-to-Build indicator[107] constructed by Joe Francis (2018a) suggests that during the period of 1880-1913 the average total value of mergers and acquisitions as a percentage of gross fixed capital formation was 5.6%. Thus, it can be safely assumed that the lion's share of differential breadth processes presented in Figure 19 were the result of external rather than internal developments, as the total

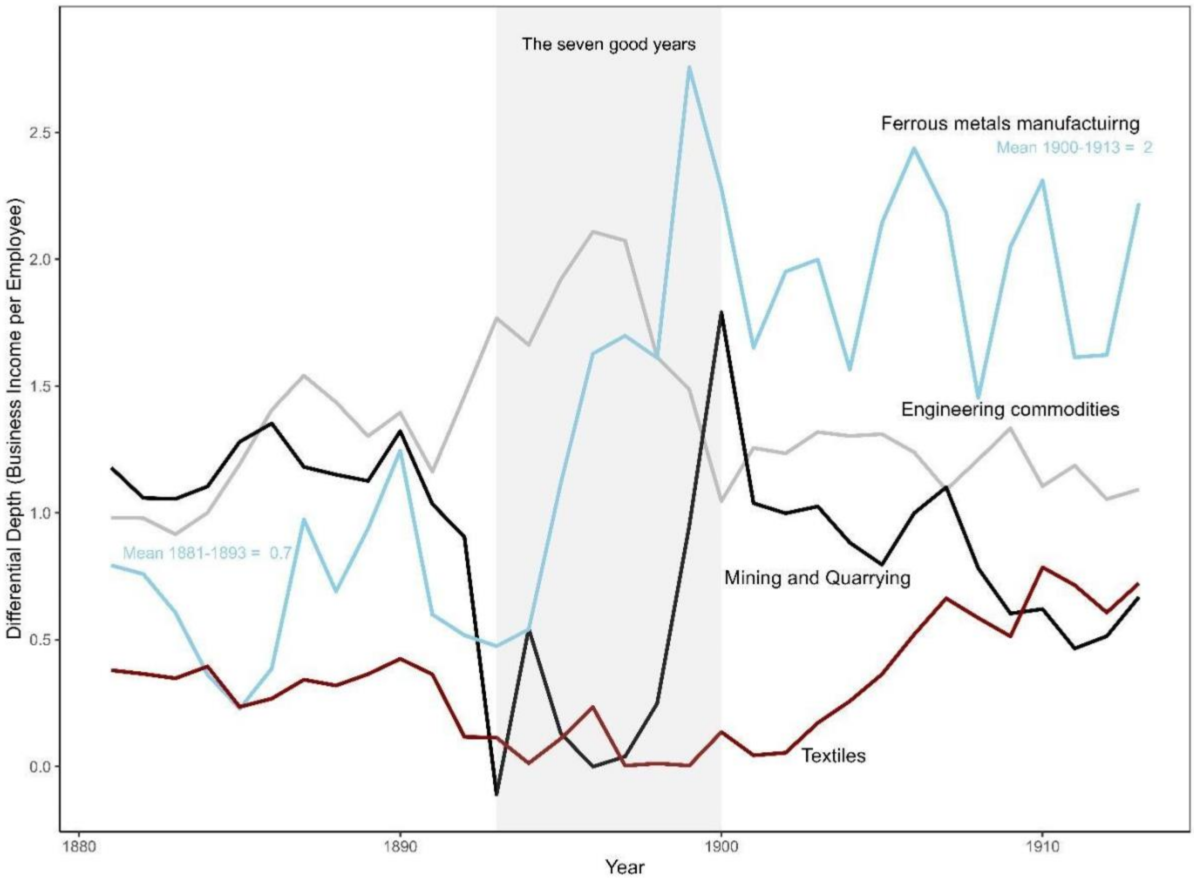
[107] The Buy-to-Build indicator is a rough measure of the ratio of internal to external breadth. It is the ratio of the value of merger and acquisition activity to gross fixed capital formation, in Francis's (2018a, 2018b) work it is expressed as a percentage.

value of the former was, on average, twenty times bigger than that of the latter throughout the period.

Turning to the study of differential depth (earnings per basic unit of operation - employee) reveals that while ferrous metals manufacturing firms did not engage in differential breadth pathways, the rise in their differential accumulation rested on internal depth pathways, specifically, enhanced differential productivity.

Figure 20 shows the differential depth (differential profit per employee) of the disaggregated energy-core industries, and of textiles manufacturing. The figure plots the ratio of a group's profit per employee to total mining and manufacturing profit per employee (see Appendix 4.3 for further details). As can be seen, throughout the energy-core's seven good years, the only significant and consistent rise in differential depth is achieved by the ferrous metals manufacturing businesses. After a rapid rise in differential depth between 1894-1899, ferrous metals manufacturing's differential depth stabilized on a new level of 2.0 on average in the period of 1900-1913 (in comparison to an average of 0.7 during the period between 1881-1893). As shown in Figure 20, it seems that differential depth did not drive engineering commodities' differential accumulation which rose and fell during the seven good years and barely changed in terms of average levels between 1881-1893 and 1900-1913 (the average level even slightly fell from 1.3 to 1.2).

Figure 20: Differential depth pathways – differential business income per employee, Britain, 1881 – 1913



Source: see Figure 13.

The following results trace the expression of the differential breadth and depth pathways (as presented in Figure 19 and Figure 20) in relative output terms.

Figure 21 depicts output indices by industry and Figure 22 presents rates of change in output by industry.[108]

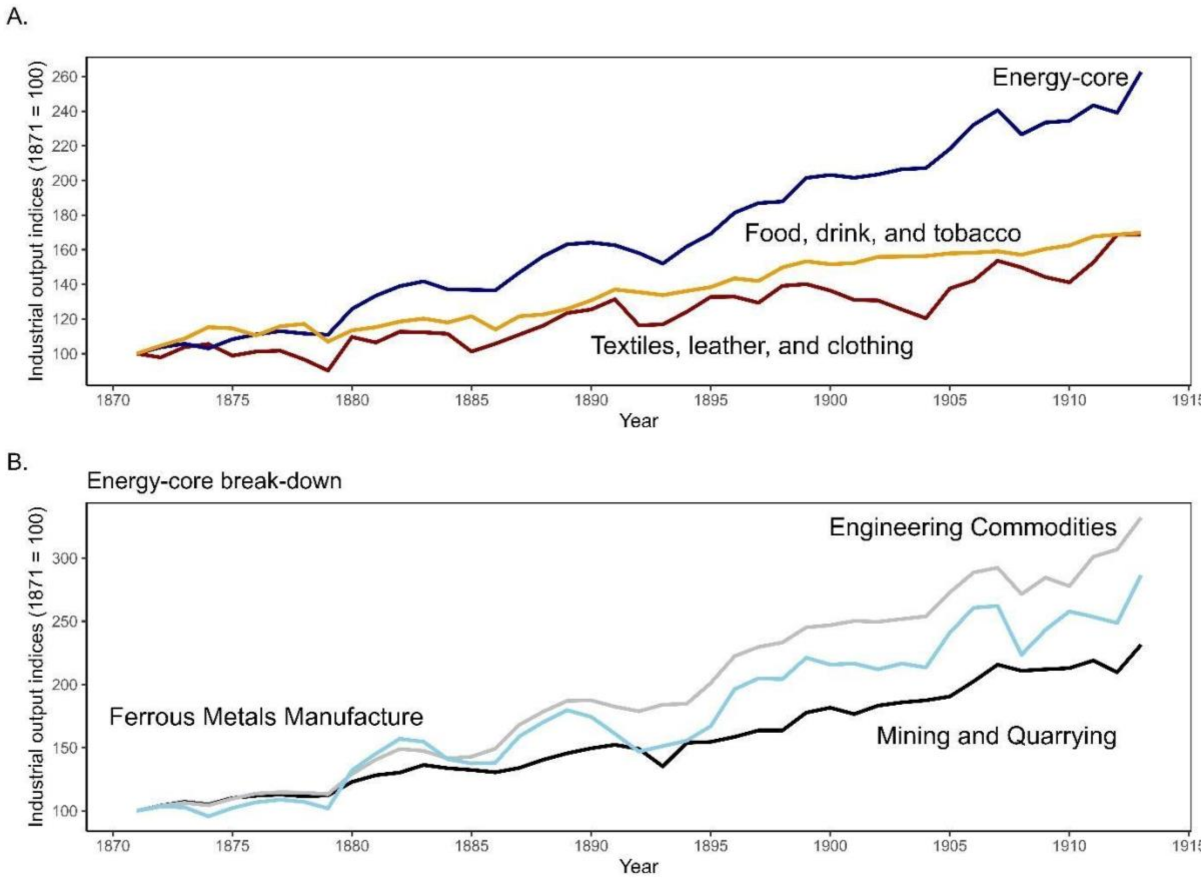
As shown in Figure 21A, between the years 1871-1913, the growth rates of energy-core output (which rose in levels by a factor of 2.6) outstripped those of food, drink and tobacco, and textiles, leather and clothing (which both rose in levels by a factor of 1.6). Meanwhile, the energy-core breakdown presented in Figure 21B shows that engineering commodities

[108] I will point out that when studying relative output, one cannot differentiate between external breadth and internal depth processes, seeing as a rise in relative (and absolute) output may be the result of either one, or a combination of the two. In other words, changes in output may stem from changes in size, productivity, or both.

manufacturing led the way in output growth, albeit ferrous metals manufacturing showed significant growth as well (a rise in levels by a factor of 3.3 and 2.9, respectively).

These results express the differential external breadth pathways (in the case of engineering commodities manufacturing), and internal depth pathways (in the case of ferrous metals manufacturing) in relative output levels, which rose faster than the average during the period of 1871-1913.

Figure 21: Output by industry, Britain, 1871-1913 (1871 = 100)



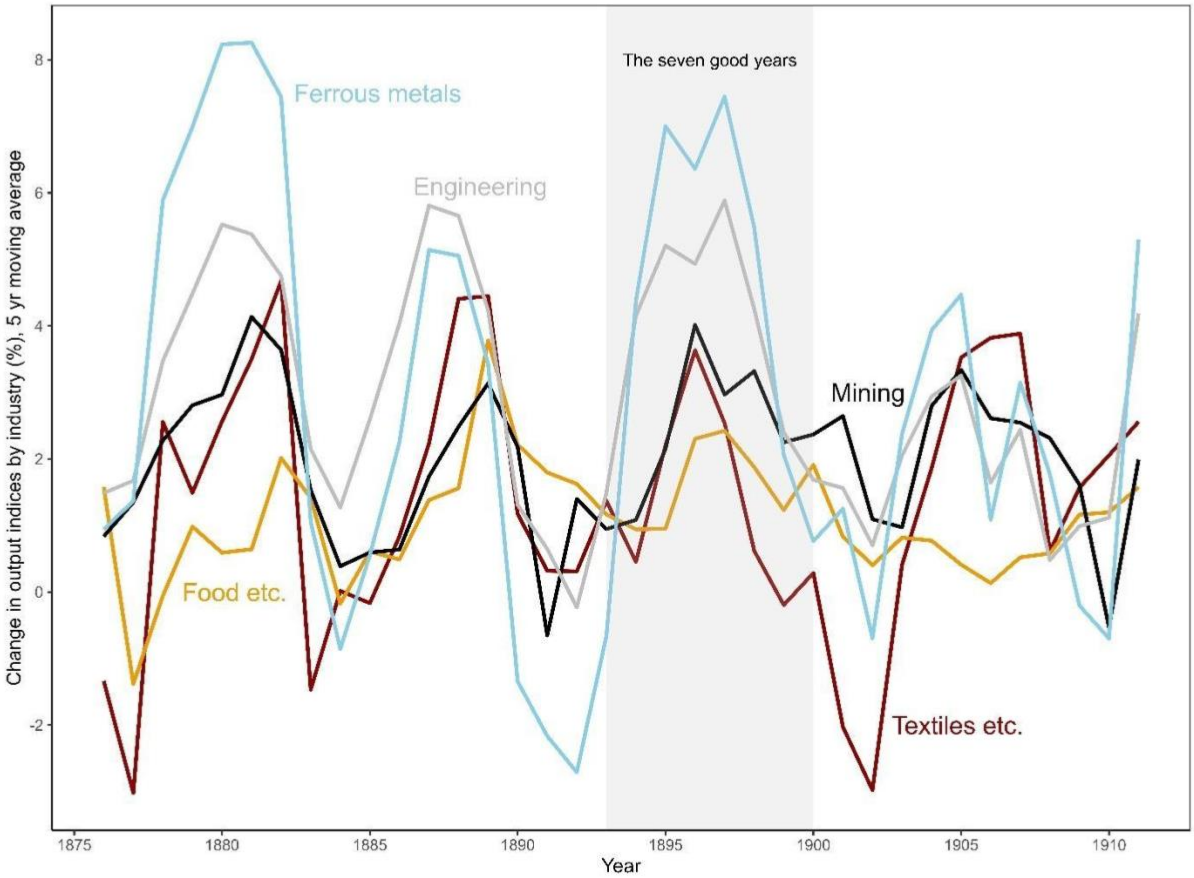
Source: Feinstein, 1972: T111, Table 51: Index of Industrial Production by Main Orders, 1855-1965.

Figure 22 presents a five-year moving average[109] of the rates of change in output by industry. The results show that during the energy-core's seven good years both ferrous metals

[109] The data is smoothed using a centred moving average, for which each data point represents the average of its value, and the values of the two preceding and the two following years.

manufacturing and engineering commodities manufacturing beat the average industrial rates of change in output, the former through differential internal depth (enhanced differential productivity), and the latter through differential external breadth (rapid differential growth in size). After the year 1900, the relatively high rates of change in output levelled off for both industries.

Figure 22: Change in output by industry, Britain, 1875-1911

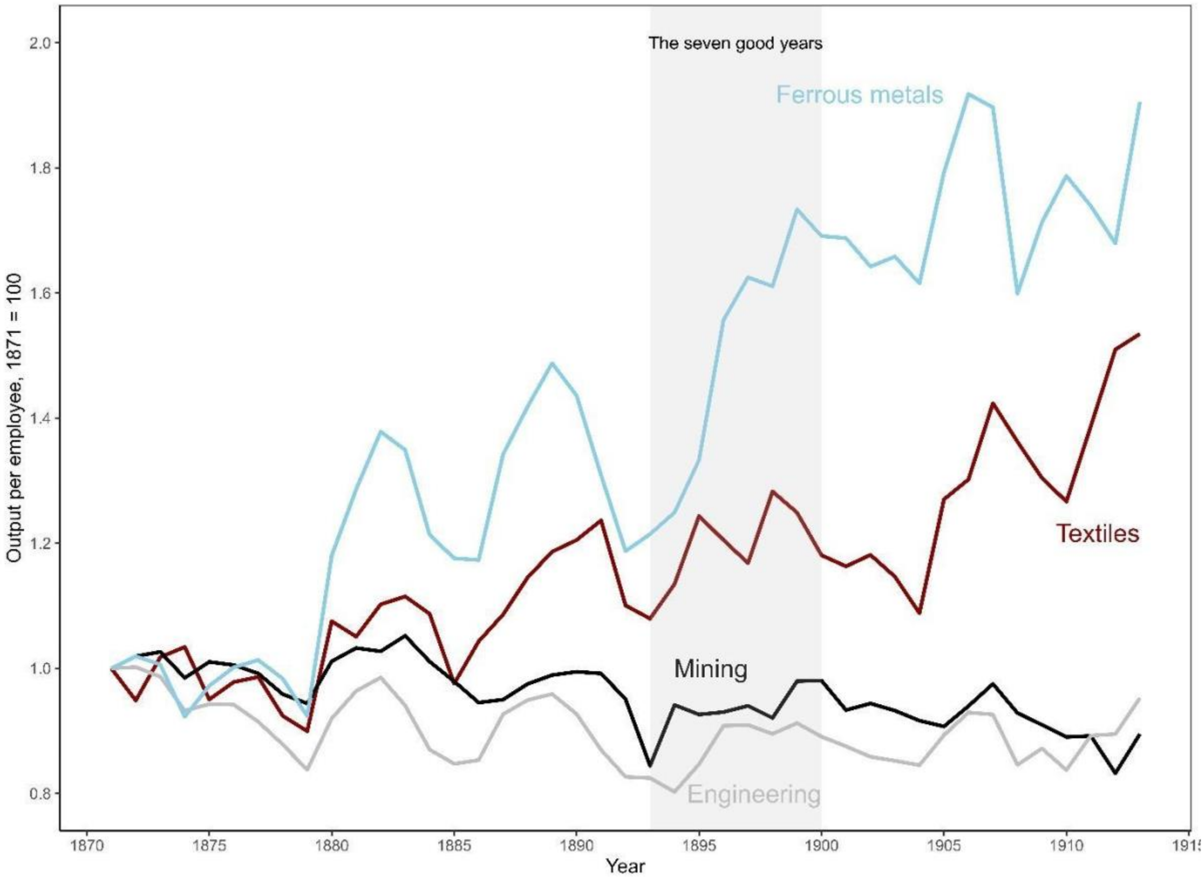


Source: see Figure 21.

The final output-based measure, presented in Figure 23, is an index of output per employee. This measure was calculated by dividing the industrial output indices by industrial employment indices. The results emphasize and confirm the claim that the differential rise of ferrous metals manufacturing during the energy-core's seven good years was based on internal depth (differential productivity) pathways, which rose rapidly during this period. As can be seen in

Figure 23, the other two energy-core sectors (mining and quarrying and engineering commodities) did not engage this pathway but rather built upon differential external breadth (as suggested in Figure 19).

Figure 23: Output per employee by industry, Britain, 1871-1913 (1871 = 100)



Sources: Output: see Figure 21. Workforce: see Figure 13.

4.3.3.2 Energy-based measures

Next, to study energy-core industries within the context of energy transition processes, I performed an analysis which defines energy units as the basic unit of operation for the differential profit formula. When we use energy units as the basic unit of operation, the differential pathways of energy-core businesses are defined in relation to their control of energy, and earnings per energy units (see 3.10.1.1).

The basic energetic unit is defined here as *energy inputs* in the manufacturing process. Hence, I will first focus on profit per ton of manufactured pig iron,[110] and later break pig iron output down according to the breadth and depth of primary energy input, i.e., total coal use in ferrous metals manufacturing, and coal use per ton of manufactured pig iron, respectively.

The ferrous metals manufacturing industry is the pivotal industry of the energy-core group, manufacturing the major intermediate energy-intensive inputs for the engineering commodities industry, and consuming large quantities of mining sector outputs, coal and iron ore, as inputs. In addition, there is both a tight correlation between ferrous metals manufacturing's GVA, and each of the other energy-core industries' GVAs (see Note to Figure 10), and between ferrous metals manufacturing's business income and each of the other energy-core industries' business income (see Note to Figure 14). Hence, I use the ferrous metals manufacturing industry to study the energy-core group's differential performance at large.

Figure 24 and Figure 25 present differential *energetic* breadth, and *energetic* depth, i.e. coal use concentration or share of coal use in total industrial coal use, and output per unit of coal use, respectively (see Appendix 4.3 for further details). The measures are presented for ferrous metals manufacturing and mining and quarrying only for reasons of data limitations.[111]

The figures show that the same trends I identified using depth and breadth analyses which define employees as the basic unit of operation hold for energy-based breadth and depth analyses: As opposed to other energy-core industries, ferrous metals manufacturing businesses engaged primarily in differential internal depth pathways (differential productivity).

In Figure 24, a *decline* in ferrous metals manufacturing's differential energetic breadth can be seen between 1869-1903. The share of iron and steel production in total industrial coal use fell

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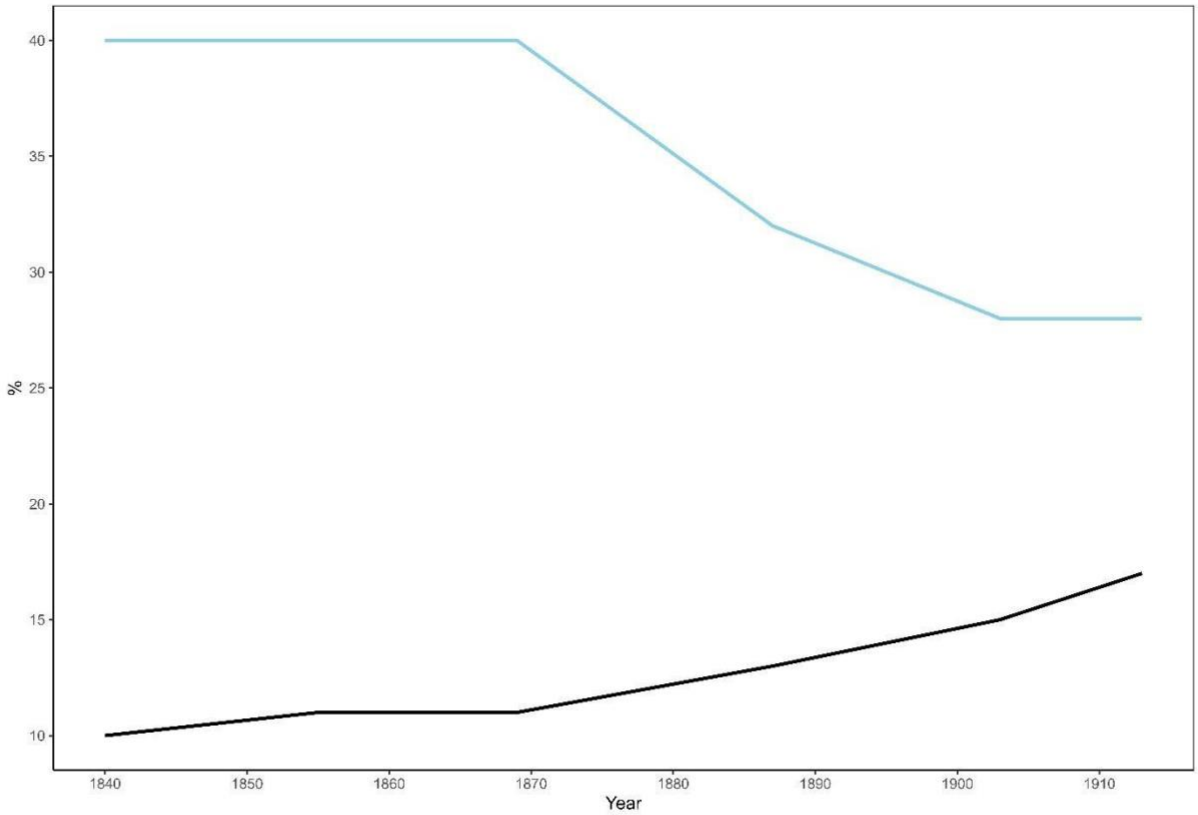
[110] Pig iron, or crude iron, is the most basic manufactured intermediate good used as an input in steel and iron manufacturing, which are later used as inputs in engineering commodities manufacturing.

[111] The most detailed disaggregation of industrial coal use in Britain before 1913 that I am aware of differentiates only coal use in iron and steel production and in mines and collieries from the general category of "other industry' which aggregates all other industrial sectors.

from 40% to 28%, while the share of mines and collieries in total industrial coal use rose from 11% to 17%.

Figure 24: Differential energetic breadth – Share in total industrial coal use, Britain, 1849-1913

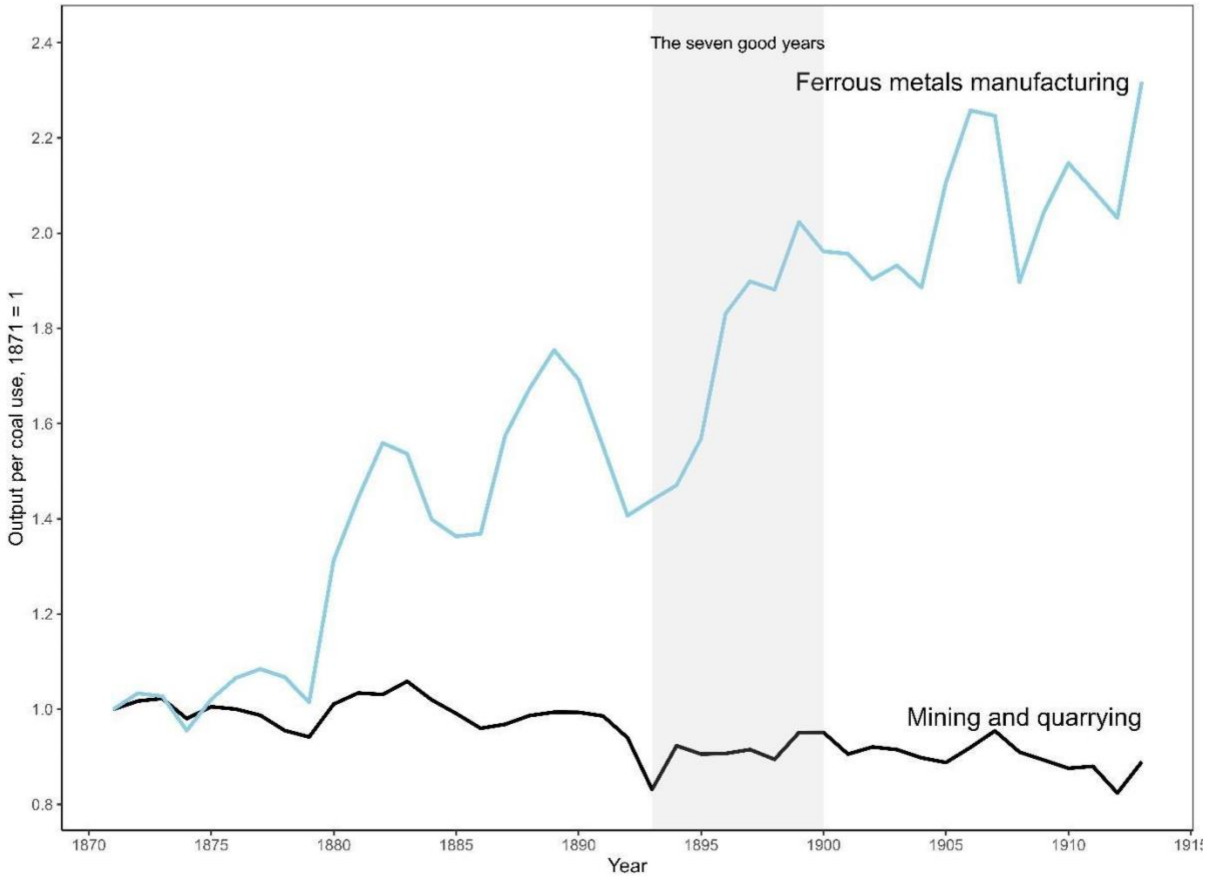


Source: Kennedy, 2020: Appendix 5, supporting data for Figure 2.

Figure 25, on the other hand, shows the rise in output per coal use (energetic depth) achieved in ferrous metals manufacturing throughout the period, and during the energy-core's seven good years in particular. During the seven good years ferrous metals manufacturing's output per coal use index rose by a factor of 1.36, from 1.44 to 1.96, stabilizing on an average level of 2.06 for the period of 1900-1913. In contrast, the mining and quarrying sector's productivity of coal use stagnated throughout the period of 1871-1913, and even slightly declined (1913 = 0.89).[112]

[112] As can be inferred from Figure 24, the share of ferrous metals manufacturing in 19th century British industrial coal use was extremely high (between 40%-28%). In light of these high shares, and the corresponding rise in energetic depth and decline in differential energetic breadth in ferrous metals manufacturing, one could venture

Figure 25: Energetic depth – output per coal use, Britain, 1871-1913 (1871 = 1)



Sources: Industrial output: see Figure 21. Industrial coal use: see Figure 24.

Figure 26 shows the rise in ferrous metals manufacturing business income per ton[113] of manufactured pig iron.[114] During the energy-core's seven good years (1894-1900), business income per ton of manufactured pig iron rose rapidly, stabilizing on a new and higher level after 1900. As show in Figure 26, Ferrous metals manufacturing business income per pig iron rose from an average of 0.5 £/Ton during the period of 1881-1983 to an average of 1.4 £/Ton during the period of 1900-1913.

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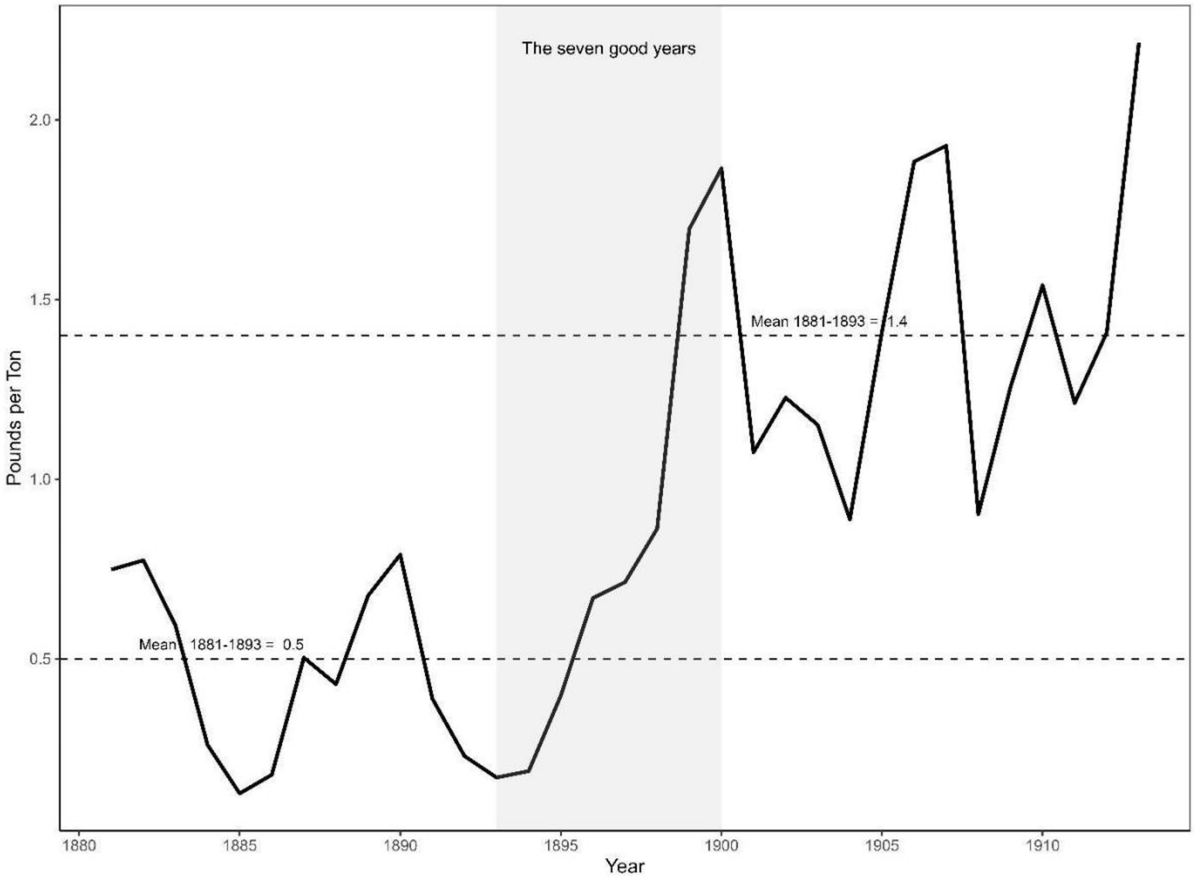
the idea that rising energetic productivity in this intermediate goods sector "released" available primary energy for use in industrial processes further down the production line.

[113] Pig iron and coal use are measured here in imperial ton units, which equal 1,016.0 kg (Kennedy, 2020).

[114] Ferrous metals manufacturing business income is derived from a range of ferrous metals products, e.g., pig iron, wrought iron products, steel products, cast iron products, etc. Nevertheless, pig iron is the main intermediate good input in the production process other ferrous metals products (albeit requiring further processing to reduce its carbon content). Assuming that the high percentage of pig iron used in final ferrous metals manufacturing products did not change significantly throughout the period, it is used to represent ferrous metals manufacturing output.

Figure 26: Ferrous metals manufacturing business income per ton of manufactured pig iron, Britain, 1887-1913



Source: Ferrous metals manufacturing business income: see Figure 14. UK pig iron production: See Figure 7.

Note that during the period in which energy-core businesses achieved differential advantage (see Figure 15 and Figure 16), the production growth rate of pig iron production, their core intermediate product, declined (see Figure 7), all the while that their income per unit of pig iron increased.

Table 19 compares the average annual geometric growth rate of the breadth and depth of energy deployment in ferrous metals manufacturing – total primary energy (coal) use, and energy productivity, or conversion efficiency, represented as coal use per manufactured ton of pig iron, respectively.[115]

[115] Note that the internal depth pathway represented by the measure of coal use per ton of manufactured pig iron relates to energy productivity only. Another internal depth pathway relates to cost cutting and might explain the differential performance of the engineering commodities industries which could take advantage of deflation processes which characterized the late 19th century in the Uk, in particular the falling prices of their main inputs

The table shows that both external energetic breadth and internal energetic depth developments accompanied the rise of British energy-core firms during the turn of the 20th century. Energy-core businesses' control of basic energy quantities externally expanded (in absolute terms) as increasing amounts of coal were deployed in ferrous metals manufacturing. All the while, the intensity of coal use in iron and steel production increased, implying a development in internal depth based on growing energy productivity.

Total coal use in ferrous metals manufacturing grew by a factor of 10.8, from 0.06% during the years 1869-1887 to 0.65% during the years 1887-1903. Yet, growth rates of total coal use in ferrous metals manufacturing were altogether *lower* during the late19th century, in comparison to the early years of its second half. Similarly, coal use per ton of manufactured pig iron decreased rapidly, at an average annual geometric rate of -1.7%, during the years 1869-1887. However, during the years 1887-1903 it decreased at a significantly slower average annual geometric rate of -0.17%.

Table 19: Average annual geometric rate of change in total coal use in ferrous metals manufacturing and coal use per ton of manufactured pig iron, Britain, 1855-1913

Years	***Total coal use in ferrous metal manufacturing***	***Coal use per ton of pig iron***
1855-1869	2.5%	-1.2%
1869-1887	0.06%	-1.7%
1887-1903	0.65%	-0.17%
1903-1913	0.97%	-0.73%

Source: Total coal use in ferrous metals manufacturing: Kennedy, 2020: Appendix 5, supporting data for Figure 2. UK pig iron production: see Figure 7.

(i.e., coal, and intermediate iron and steel products) (Mitchell, 1964). This point will be addressed in the following section.

To conclude, within the energy-core a significant divergence can be detected: the mining and quarrying sector was not part of the rise in differential accumulation (in terms of income, productivity, output, and employment).[116] Meanwhile, within the leading energy-core businesses, engineering commodities manufacturing relied mainly on rapid external breadth (with barely any differential productivity gains), while ferrous metals manufacturing relied primarily on internal depth and enhanced productivity in production processes.

I argue that the techno-physical processes presented above were tightly related to energy-core businesses' ability to engage in differential price hikes. More specifically, it could be related to an early price-making mechanism derived by ferrous metals manufacturing firms. Recall that though differential productivity (both energetic and per employee) and external breadth processes (again, both an expansion in the control of energy units and of employment) can be detected as far back as the 1880's, and even late 1870's, it was only during the second half of the 1890's that these were leveraged by the energy-core to attain (and preserve) a new and higher level of differential profit.

It seems that while throughout the 1870's and 1880's internal depth and external breadth pathways did not result in stable differential accumulation, during the seven good years (1894-1900), a potential to control differential prices was realized by the energy-core. This shift to monetary measures coincides with the *decline* in the development of energy conversion efficiency in energy-intensive manufacturing processes. In this sense, the tightening and refining of business control of industry marked the closing of the era's transformative socio-technical window of opportunity.

To better understand the energy-core's rapid differential accumulation throughout the seven good years, I turned to a final set of differential monetary measures.

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[116] It may be of significance that the mining and quarrying sector was characterised by high union density (the percentage of trade union members within the total workforce). By 1892, 52% of mining and quarrying labourers were unionized, while the general union density in GB was 13% (Hatton, et al., 1994: 436, Table 1: Trade Union Membership in Britain, 1888 and 1892). which drove wages up and complicated the control of labour

4.3.3.3 Enter external depth – monetary differential accumulation measures

The energy-core's seven good years mark a period of critical change. Within it, the potential to control differential pricing coincides with a period of retardation in the rampant transition to fossil fuels. During the crux of this period, energy-core industries reverted to external depth measures - achieving rapid differential accumulation through the differential inflation of output prices in relation to energy inputs prices and wages. Thus, led by ferrous metals manufacturing businesses, the energy-core succeeded in differentially raising output prices in relation to the prices of two of its core inputs - labour and coal. In a sense they can be thought of as forerunners of the price-making techniques of the 20th century, and mature forms of differential capital accumulation. This section presents the results that support this claim.

Table 20 displays half-decadal averages of UK price indices between 1871-1911. As can be seen in the table, and as elaborated on in Section 3.7.1.2, the period between 1873-1896 was deflationary and characterized by falling output prices. For textiles, food, and the general price indices, average half-decadal prices started to rise only between 1901-1905. The two price indices whose half-decadal averages do rise throughout the 1890's are the energy-core's coal and pig iron.

Nevertheless, a closer look at the numbers shows that the pig iron price index growth outstripped that of coal during the energy-core's seven good years. The half-decadal pig iron index rose by 23.5% between the first and second halves of the 1890's, while the average half-decadal coal price index rose only by 4.1%. And so, a differential output price increase during the second half of the 1890's led by ferrous metals manufacturing was detected.

Table 20: UK half-decadal average price indices, 1871-1911

Years	***Coal***	***Pig Iron***	***Textiles***	***Food***	***All***
1871-1875	157.2	149.2	105.6	103.6	106.2
1876-1880	98.8	95.3	89.8	100.9	97.7
1881-1885	93.5	83.3	81.2	91.4	88.7
1886-1890	98.1	78.0	70.3	75.8	75.0
1891-1895	108.5	80.6	63.7	74.3	72.5
1896-1900	113.0	99.6	60.5	68.1	68.4
1901-1905	122.5	102.9	69.2	70.0	71.7
1906-1910	122.4	112.3	82.9	73.8	77.1

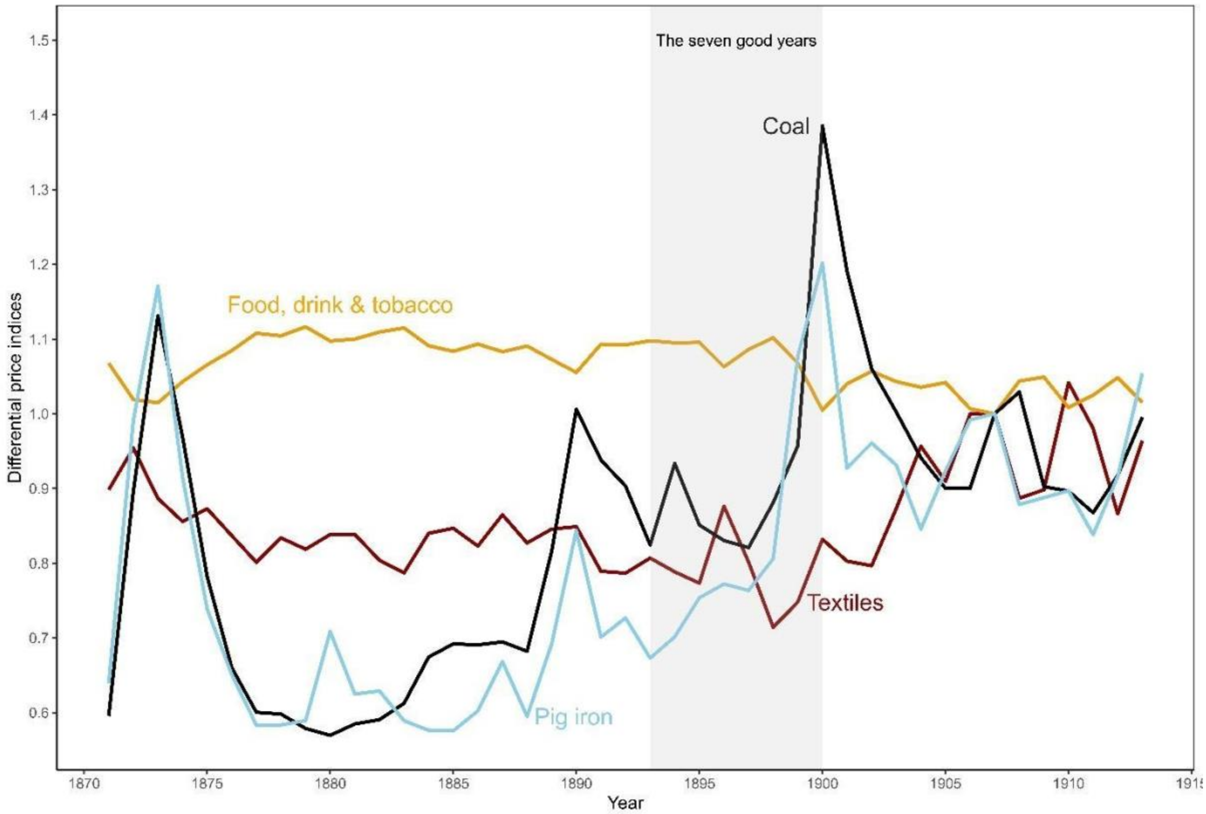
Source: Great Britain Board of Trade, 1903: xxxviii: Unweighted percentage variations in prices: group 1 – coal and metals, and Great Britain Board of Trade (department of labour statistics), 1915: 88-89, Index Numbers for Wholesale Prices: All Groups and Index Numbers for Wholesale Prices: coal and metals.

Figure 27 and Figure 28 present two differential monetary depth measures – differential output prices, calculated as the ratio of different disaggregate price indices to the general price index, and differential average annual wage, calculated as the ratio of the average annual wage in different sub-industries to the average annual wage in manufacturing. As opposed to the physical and employment-based measures presented in the previous section, these figures represent monetary differential accumulation measures corresponding to external depth (differential pricing and inflation).

As can be seen in Figure 27, the price of ferrous metals manufacturing's basic output (pig iron) began to differentially rise as the energy-core entered its seven good years, once more stabilizing on a new and higher level in the period directly after the rapid rise (an average of 0.7 between 1875-1893 and an average of 0.9 between 1900-1913).

Significantly, pig iron's differential price rise precedes that of coal, the only other output whose prices beat the general average during the late 19th century, and a major input in ferrous metals manufacturing. Textile products and food, drink and tobacco differential prices stagnated throughout this period.

Figure 27: Differential output prices, selected industries, Britain, 1871-1913



Source: see Table 20.

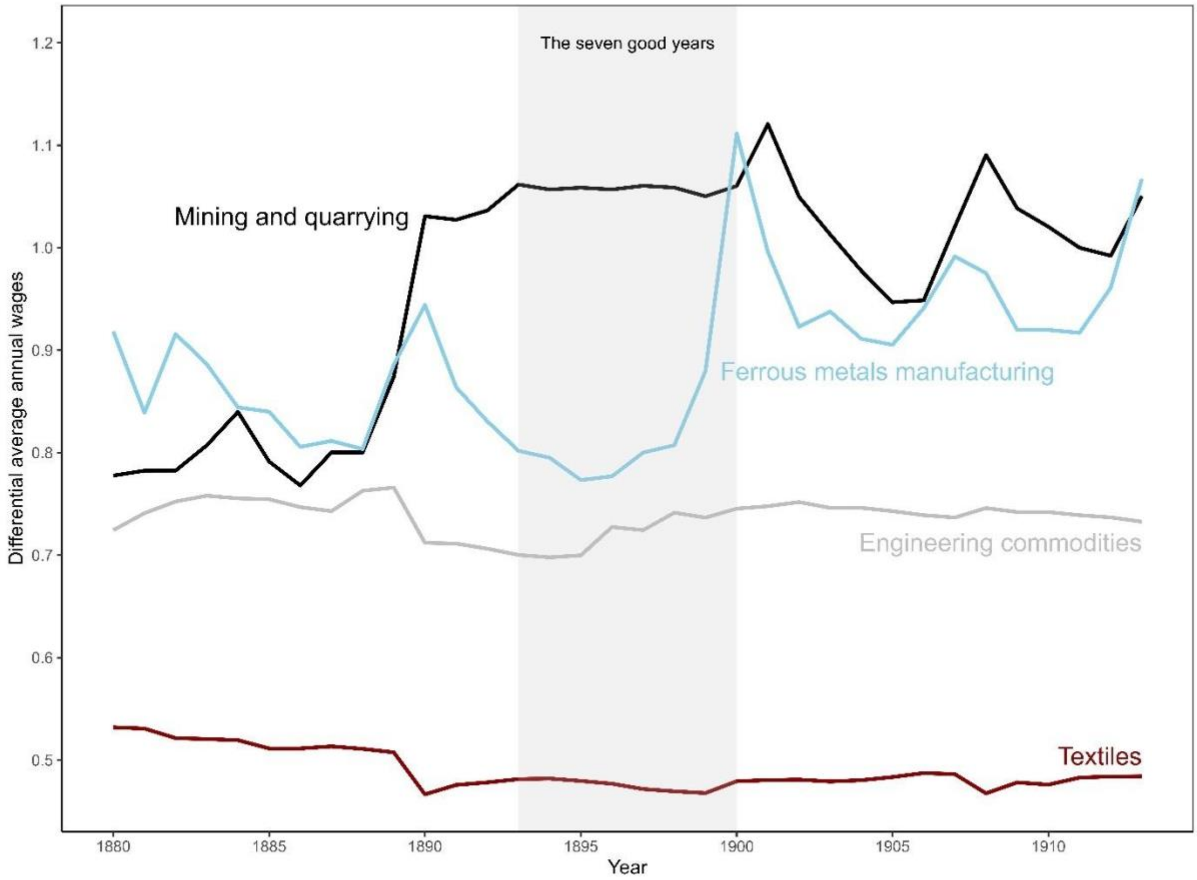
Figure 28 presents a measure of differential average annual wage. In this figure, the different pathways undertaken by the three energy-core industries are clearly depicted. The mining and quarrying sector did not partake in the energy-core's differential accumulation surge during the seven good years. As apparent from the graph, the long-standing, highly unionized mining and quarrying workforce (see Footnote 116) gained a significant increase in differential average annual wages at the beginning of the 1890's (relative to the average annual general manufacturing wages level), thus presumably offsetting differential business gains from recovering coal prices (see Table 20).

Though the general average wage level rose steadily over the period of the late 19th century (Allen, 2009), the engineering commodities and textiles industries' differential average annual wage were virtually flat throughout the period. Considering engineering commodities manufacturing's relative rise in output (see Figure 21 and Figure 22) and differential breadth (employment) (see Figure 19), this stable differential wage level contributed to differential accumulation.[117]

Ferrous metals manufacturing on the other hand, displays a differential wage rate reminiscent of its differential price (see Figure 27) and differential business income per employee (depth) trends (see Figure 20). This relates to the differential productivity pathway it had embarked on. During the energy-core's seven good years ferrous metals manufacturing productivity rose rapidly between 1893-1898 (see Figure 23 and Figure 25). Ferrous metals manufacturing differential wage levels only started to rise slightly in 1896 and began a sharper ascent only in 1899. These corresponding processes accompanied ferrous metals manufacturing's differential accumulation during the seven good years. Figure 29 will further explore these findings.

[117] Differential accumulation is related here to a downwards pressure of engineering commodities businesses on wages, which kept wages differentially stable (see Figure 28) while engaging in differential external breadth (increasing in size faster than others) (See Figure 19).

Figure 28: Differential average annual wage, Britain, selected industries, 1880-1913



Sources: see Figure 13.

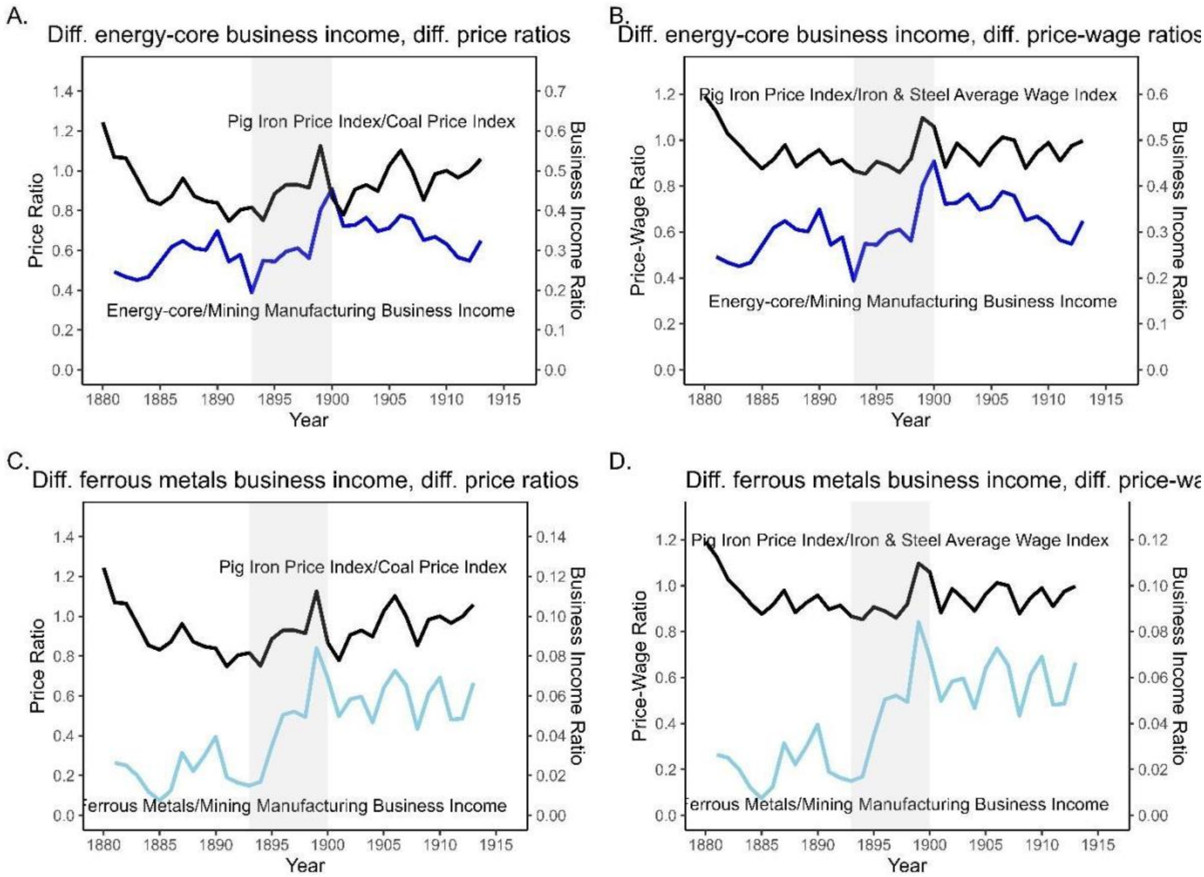
Figure 29 contains four panels and is designed to uncover part of the mechanism behind ferrous metals manufacturing firms' price-making shift. Panels A and B compare relative energy-core business income (plotted in blue) to differential pig iron prices (calculated as the ratio of the pig iron price index and the coal price index), and to the ratio of pig iron prices to average annual wages in iron and steel manufacturing, respectively. Panels C and D present the same for differential ferrous metals manufacturing business income (plotted in light blue).

The price ratio plotted in black in Panels A and C represent the relative output to energy input prices in ferrous metals manufacturing (pig iron to coal, respectively). The price/wage ratio plotted in black in Panels B and D represent the relative output prices to average wages in ferrous metals manufacturing (pig iron to annual average iron and steel manufacturing wages, respectively).

And so, Panels C and D compare ferrous metals manufacturing relative business income to its output/input price ratios, and Panels A and B compare the energy-core's relative business income to the same, using ferrous metals manufacturing price ratios as a proxy.

As can be seen in the Panels A and C, ferrous metals manufacturing relative business income rose in tandem with the differential rise of pig iron prices in relation to coal prices during the energy-core's seven good years (1894-1898). This finding indicates that, after half a decade of deflation and falling prices, energy-core firms succeeded in raising their differential profit margins, by raising the price of pig iron faster than the price of one of their core inputs (coal). In addition, Panels B and D show that the ratio of pig iron prices to average annual iron and steel wages rose between 1898-1900, indicating that as part of the business shaping of profits, prices of pig iron were raised faster in relation to wages. The analysis presented in Figure 29 begins to reveal the price-making mechanism behind the energy-core's differential accumulation and will be further consider in the discussion section (Section 7.2).

Figure 29: Differential business income and differential price ratios, Britain, 1881-1913



Note: Differential business income is plotted against the right Y axes, differential prices are plotted against the left Y axes. Source: Differential business income: see Figure 15 and Figure 17. Price indices for pig iron and coal: Great Britain Board of Trade (department of labour statistics), 1915: 89, Index Numbers for Wholesale Prices: coal and metals. Average annual iron and steel wages: see Figure 13.

To conclude, during the 19th century in Britain, a coupled growth in the breadth and depth of energy capture took place, following an s-shaped logarithmic pattern. The late 19th century was a period of retardation in the transition to fossil fuels (Section 4.1, Figure 4 - Figure 8, Table 14 - Table 16). The transformation in the energy regime went hand in hand with a gradual reorganisation of the industrial structure and the business form, i.e., a general increase in business centralization, corporatization and the larger use of credit (Section 4.2, Figure 9). However, this was not only a process of general change and reorganization of business and industry.

At the very end of the 19th century (1894-1900) the energy-core (Section 4.3.1 Figure 10 - Figure 12, Table 17) experienced a period which I termed the *seven good years* during which they achieved differential accumulation, which later stabilized on a new and higher level of relative profit after 1900 (Section 4.3.2, Figure 13 - Figure 18, Table 18).

The two main business pathways which accompanied the rapid transition to fossil fuels during the second half of the 19th century were external breadth and internal depth (enhanced productivity). However, these were initially difficult to control and leverage in differential accumulation. Indeed, during the 1870's and 1880's external breadth and internal depth did not result in stable differential accumulation for any group because potential differential gains were offset by falling output prices. This changed during the 1890's when the energy-core entered its seven good years, by leveraging and fulfilling a potential to control differential prices. During these years, and in contrast to the earlier period, energy-core's differential prices and differential output moved in tandem. In this changing industrial context energy-core firms succeeded in shaping prices so as to increase their differential profit margins (Figure 29). Within the energy-core a significant divergence can be detected: the mining sector was not part of the differential rise (in terms of income, output, and employment), it was also characterised by high union density which drove wages up and complicated the control of labour. Meanwhile, within the leading energy-core businesses, engineering commodities manufacturing relied mainly on rapid external breadth (with barely any differential productivity gains), while ferrous metals manufacturing relied primarily on internal depth and enhanced productivity in production processes (Figure 19 - Figure 26, Table 19).

After the rapid differential accumulation period of 1894-1900, energy-core firms' differential position stabilized on a new level during the pre-WWI period (Figure 15 and Figure 16). This new level provided the differential starting point for the further consolidation of dominant capital in the age of oil. The energy-core's early differential rise corresponds with slowing growth rates in energy-intensive resources and materials output, as well as in the conversion efficiency of technologies which drove the initial stages of the energy transition to fossil fuels. It was in this context that, led by ferrous metals manufacturing, the energy-core reverted to external depth measures - achieving rapid differential accumulation through the differential inflation of output prices in relation to energy inputs and wages (Figure 27 - Figure 29, Table 20). The following section will trace the second stage of the consolidation of the energy-core as a dominant capital group during the 20th century's interwar years.

4.4 Into the 20th century: The consolidation of power, differential accumulation regime cycles, and sociotechnical change

Though the turn of the 20th century witnessed its rise, energy-core dominant capital in Britain had yet to establish its power. The findings presented below suggest that the flourishing of the energy-core's next generation of industries in the age of oil and warfare, (i.e., petrochemicals and other chemicals, automobiles, electricity, and construction in the context of rapid urbanization, alongside traditional energy-core industries), was kickstarted by the initial, turn of the century bout of differential accumulation.

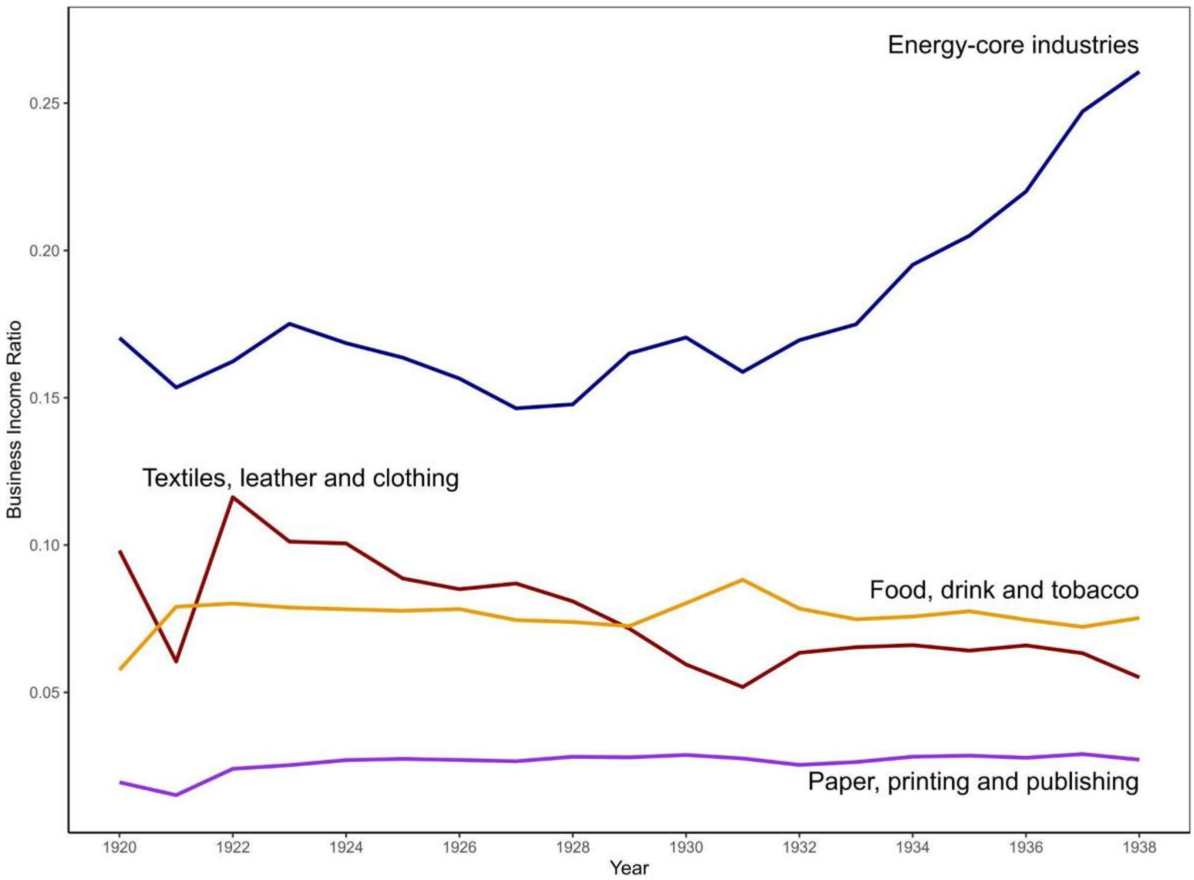
Figure 30 and Figure 31 explore the proceeding interwar phase of the energy-core's[118] differential accumulation and dominant capital consolidation. Figure 30 presents the differential profit shares of energy-core businesses and other manufacturing industries calculated as the quotient of a group of industries' gross trading profits (see Footnote 100) and total non-agricultural trading profits (including all sectors of the economy save for agriculture).

[118] The measures for the years 1920-1938 represent a wide definition of the energy-core (which I was unable to achieve for the pre-WWI years due to data constraints). For this period the energy-core group contains mining and quarrying, energy-intensive manufacturing (i.e., metals manufacturing, engineering commodities, shipbuilding, electrical goods, vehicles, chemicals, and building materials), and energy-intensive utilities (i.e., electricity and gas). These industries represent the second phase of energy-core dominant capital consolidation.

As Figure 30 shows, that profit shares of food, drink, and tobacco manufacturing, and paper, printing, and publishing barely changed throughout the postwar period, stagnating at the average level of 7.6% and 2.6%, respectively. The profit share of textiles, leather, and clothing dropped by a factor of 2, from 12% in 1922 to 5.6% in 1938.

In contrast, the energy-core's profit shares rose throughout the second half of the interwar period, increasing from 14% in 1928 to 26% in 1938. Thus, building on turn-of-the-century achievements, energy-core dominant capital continued its differential accumulation trajectory, achieving ever higher levels.

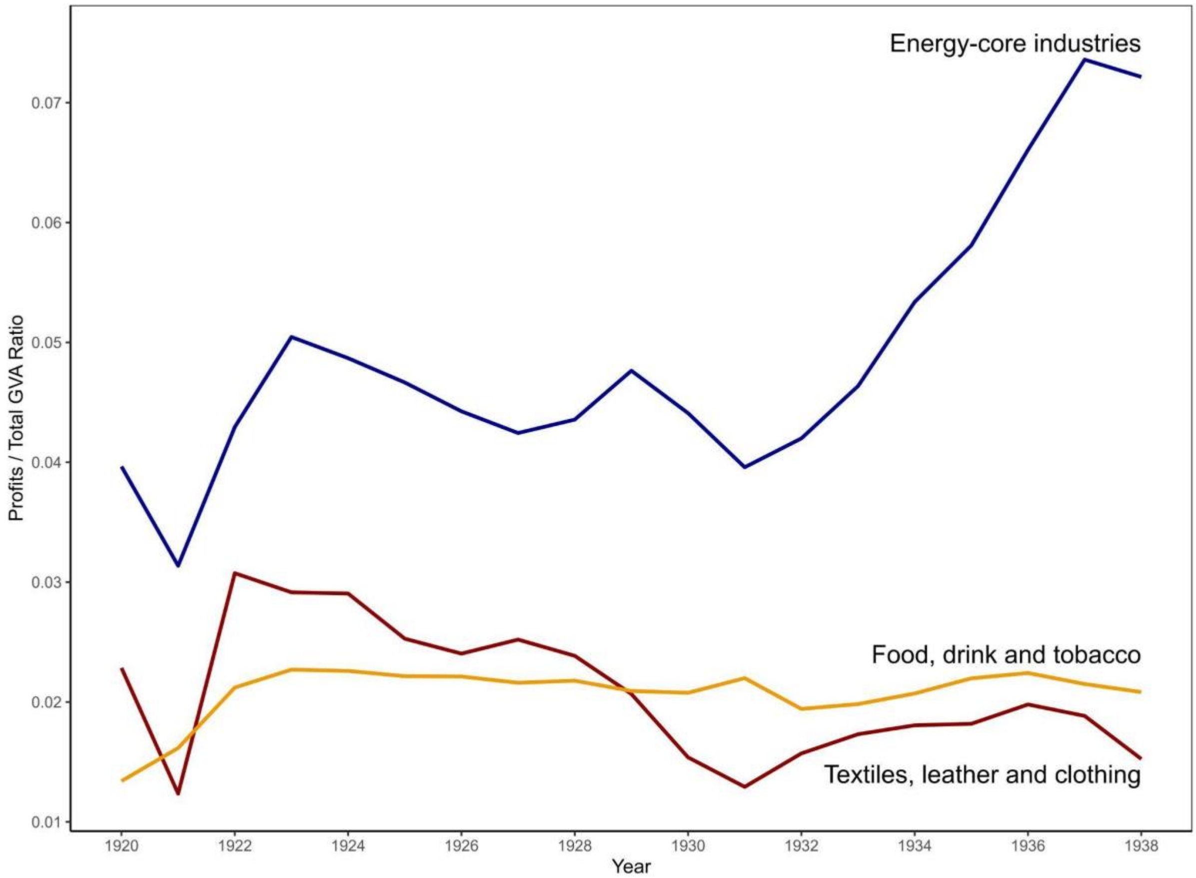
Figure 30: Differential trading profits, UK industries, 1920-1938



Source: Feinstein, 1972: T71-T72 – Table 27: GROSS TRADING PROFITS OF COMPANIES, PUBLIC CORPORATIONS, LOCAL AUTHORITY TRADING ENTERPRISES; AND NON-FARM INCOME FROM SELF-EMPLOYMENT, 1920-38 Manufacturing and other Industries.

Figure 31 compares the approximated profit margins[119] of energy-core businesses and other manufacturing industries in the UK. As can be seen, the energy-core's second differential rise in profit shares corresponds to a rise in its approximated profit margins, from 4% in 1931 to 7.2% in 1938. During the same period food, drink, and tobacco approximated profit margins stagnated at an average of 2%, while the textiles, leather, and clothing industries' approximated profit margins dropped from around 3% in 1922 to 1% in 1938.

Figure 31: Approximated industrial profit margins, UK, 1920-1938



Source: Trading profits: see Figure 30. Total non-agricultural GVA was calculated by adding trading profits to total industrial labour income from: Chapman & Knight, 1952: 68-123: Tables 38-40 – Mining and quarrying salaries and wages, Table 45 – Manufacturing salaries and wages, and 53 – Utilities salaries and wages. And from Feinstein, 1972: T57-T59: Table 22: Income from employment by industry.

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[119] Approximated profit margins are calculated as the ratio of industrial trading profits to total non-agricultural GVA. The total non-agricultural GVA is used as the denominator to account for all inputs in the production process (save for imported inputs).

It could be argued that the co-movement of profit shares and profit margins presented in Figure 30 and Figure 31 indicate that the second stage of the energy-core's differential accumulation during the inter-war years was based on differential depth strategies, i.e., differential pricing which marked-up the energy-core's output prices in relations to costs as well as average output prices. In a sense, this era marked the maturation of the price-making mechanisms pioneered by the ferrous metals manufacturing firms as the 19th century drew to a close. I will explore these claims further in Section 7.2.

4.5 Conclusion of British case-study results

To conclude, the results of the British case study analysis presented in this chapter tell the story of the coupled energy transition to fossil fuels and maturation of the capitalist mode of power. The rapid rise in breadth and depth of energy capture throughout the 19th century was associated with *general* external breadth and internal depth business processes which enabled the *general* shift toward growth in the size of business institutions, corporatization, and the larger use of credit (Section 4.2, Figure 9).

However, though this era of high and seemingly untameable growth rates was instrumental in advancing these business-industry developments in general, it seems that *differential* growth processes were harder to achieve under these conditions. It was only during the late 19th century that the techno-industrial conditions for differential accumulation were attained. This period was characterized by a declining rate of change in transformative energy capture processes (Figure 4 - Figure 8, Table 14 - Table 16) which enabled an increasing refinement of business control of industry.

During the late 19th century energy-core industries began appropriating differentially higher shares of fossil-fuel-related resources and capacities (Table 17) and business income (Figure 13 - Figure 18). Energy-core firm's differential accumulation process really took off during the "seven good years" between 1894-1900 when, led by ferrous metals manufacturing, they succeeded to differentially shape prices to their advantage, in relation to their core input prices and labour income (Figure 27 - Figure 29, Table 20). This initial surge of energy-core firms' differential accumulation at the turn of the 20th century created the basis for the second surge and consolidation of dominant capital during the interwar years of 1920-1938, when energy-core firms achieved yet higher levels of differential income and profit margins (Figure 30 and Figure 31).

5. Conventional recovery pathways: leveraging the threat to reliable electricity supply

In this chapter, I present and discuss the results of the German *Energiewende* case study analysis which uses the conceptual tools developed and presented in Section 3.10.1.2 and Appendix 5. The chapter is divided into four complementary parts: 1. Tracing conventional recovery presents financial data analysis; 2. Uncovering differential depth consists of accounting records and physical data analysis; 3. Conventional ownership concentration analysis is based on accounting records data analysis; and 4. Revealing the sabotage mechanism combines accounting records and physical data analysis.

The German *Energiewende* case study analysis examines the second group of hypotheses (Hypotheses 3-5) and explores the connection between internal-depth-based differential accumulation and increased path-dependency, as suggested in Hypothesis 2.

5.1 Tracing conventional recovery

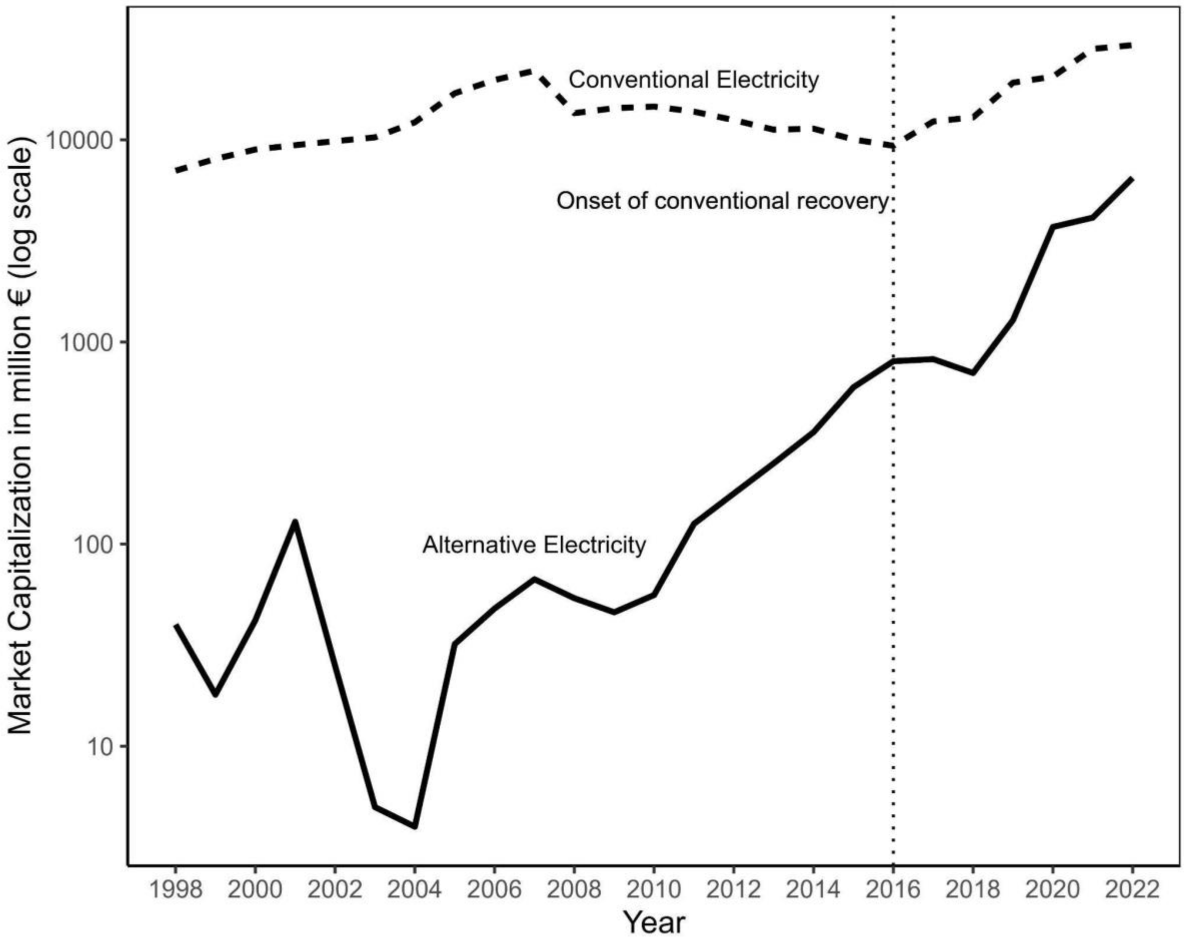
The following results first drew my attention to a change in the differential financial performance of German conventional electricity firms beginning in 2017. The analysis is based on two Refinitiv Eikon Datastream indices: Germany Conventional Electricity and Germany Alternative Electricity. For further details on the indices, see Appendix 1.

Figure 32 shows the market capitalization[120] of the two indices plotted against each other. As is evident from this figure, following the expected stagnation in conventional electricity market capitalization between the global financial crash of 2008 and 2016, the conventional market

[120] Market capitalization, also known as market cap, in a measure of the total value of a publicly traded company's outstanding shares owned by stockholders. It is calculated by multiplying the number of outstanding shares by the price per share.

capitalization began to steadily rise in 2017. Notably, this rise *preceded* the rise in the alternative market capitalization, which, after a short period of stagnation starting in 2016, was renewed only in 2019. Note that although the log scale shows the gap between conventional and alternative market cap shrinking rapidly, the German Conventional Electricity Index market cap is in fact still an order of magnitude larger than that of the German Alternative Electricity Index.[121]

Figure 32: Germany Electricity Indices - Market capitalization, 1998-2022

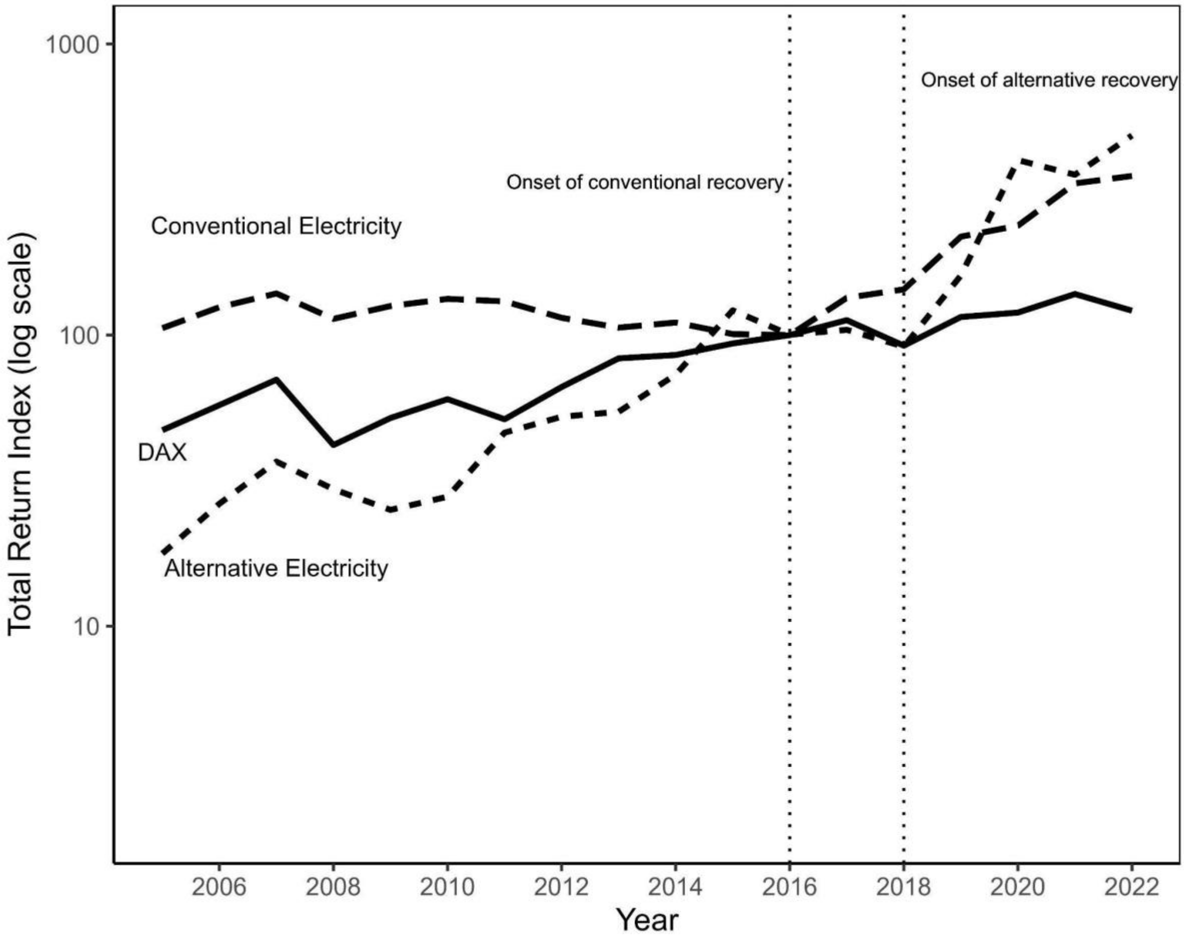


Note: Values are expressed on a log10 scale. Sources: Datastream International (25.8.2023); Available: Rifinitiv Workspace; Germany conventional electricity market capitalization: GERMANY.DS.Conv.Electricity...MARKET.VALUE ; Germany alternative electricity market capitalization: GERMANY.DS.Alt..Electricity...MARKET.VALUE.

[121] While Alternative market cap lies between 0-3,700 million €, Conventional market cap lies between 1,000-20,000 million €.

A broader financial measure, the Total Return Index (TRI),[122] shows the same trend. Figure 33 shows the TRI of Datastream's Germany Conventional Electricity and Germany Alternative Electricity indices, as well as the DAX Performance index (DAX.PERFORMANCE), which acts as a benchmark and is based on the German stock market. The values are normalized to 2016, a year before the upward conventional trend begins. As shown in Figure 33, also in terms of total return, the conventional index began to rise steadily in 2017, after a decade of stagnation and decline. The alternative index began to rise again only in 2019.

Figure 33: DAX and Germany Electricity Indices – TRI, 2005-2022 (2016 =100)



Note: Values are expressed on a log10 scale and normalized to 2016 = 100.

Sources: Datastream International (25.8.2023); Available: Rifinitiv Workspace; Germany conventional electricity TRI: GERMANY.DS.Conv.Electricity...TOT.RETURN.IND; Germany alternative electricity TRI : GERMANY.DS.Alt..Electricity...TOT.RETURN.IND; DAX PERFORMANCE TRI : DAX.PERFORMANCE...TOT.RETURN.IND.

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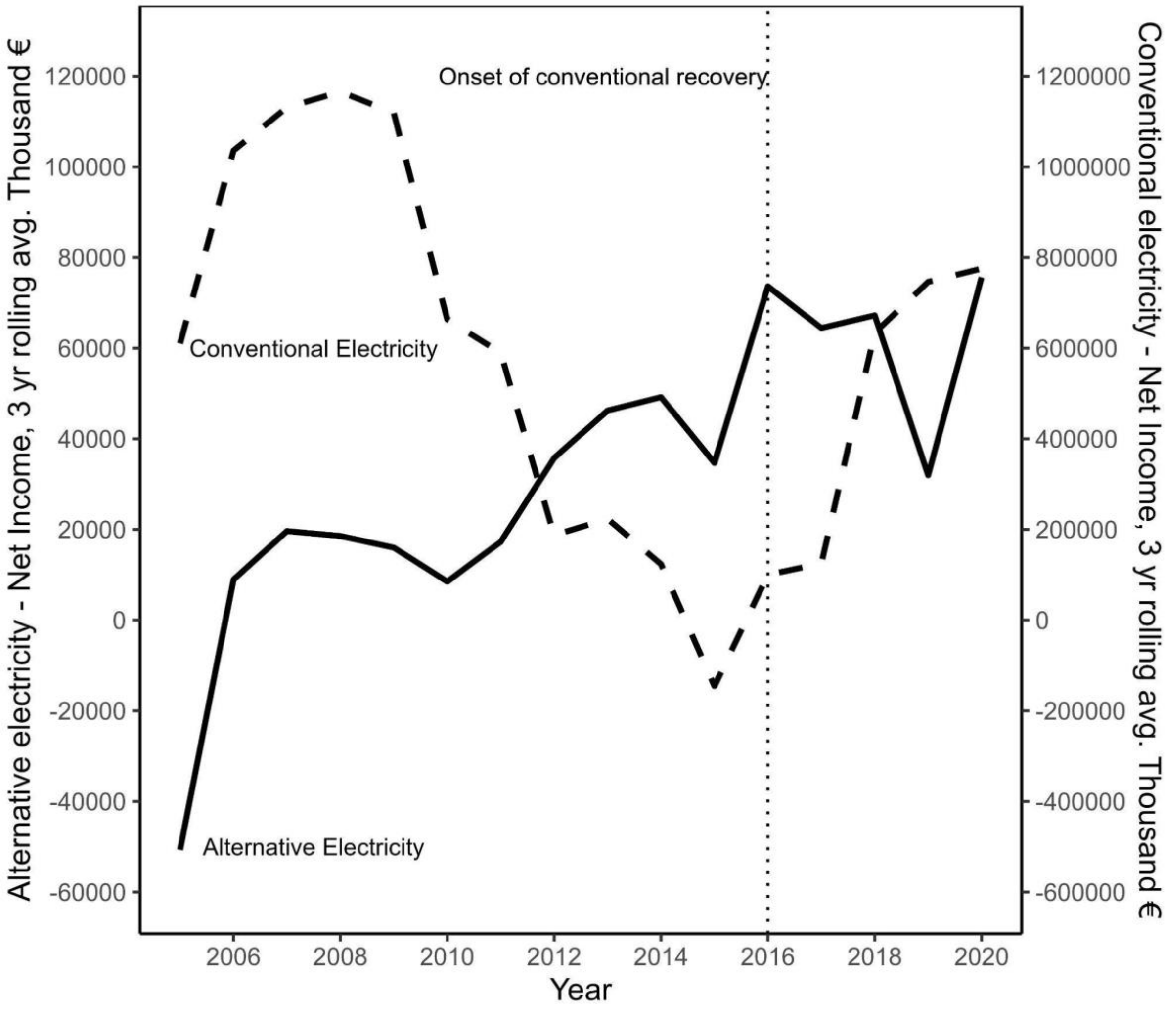
122 The total return index is a comprehensive stock market index that tracks both capital gains (i.e., profits from investment or the sale of property) and cash distributions (e.g., dividends, interest, etc.).

Finally, Figure 34 shows that the same trends hold for net profit.

These results support Hypothesis 3, according to which early *Energiewende* trends of decentralization and RES-based decarbonization trends initially hampered the dominant position of the major German CEG firms. Yet, as suggested by Hypothesis 4, a compensation for this initial destabilization seems to take place in 2016, as relative capitalization and income trends begin to change.

Figure 34: Electricity Indices - Net Income (3-year rolling average), 2005-2022



Note: Germany conventional electricity index is plotted against the right axis, Germany alternative electricity index is plotted against the left axis. Values are expressed as 3-year rolling averages.

Sources: Datastream International (25.8.2023); Available: Rifinitiv Workspace; Germany conventional electricity net profit: GERMANY.DS.Conv.Electricity...NET.PROFIT.INCOME.; Germany alternative electricity net profit: GERMANY.DS.Alt..Electricity...NET.PROFIT.INCOME.

Note that in Figure 34, the rise in conventional net income appears to begin in 2016. This is due to the 3-year rolling average, used to smooth out the data, in which every datapoint expresses the average of the current year, the preceding year and the following year. Alternative net income does not show a secular growth trend after 2016.

The apparent differential recovery of conventional electricity firms, and the growth in their differential income sent me looking deeper for its causes.

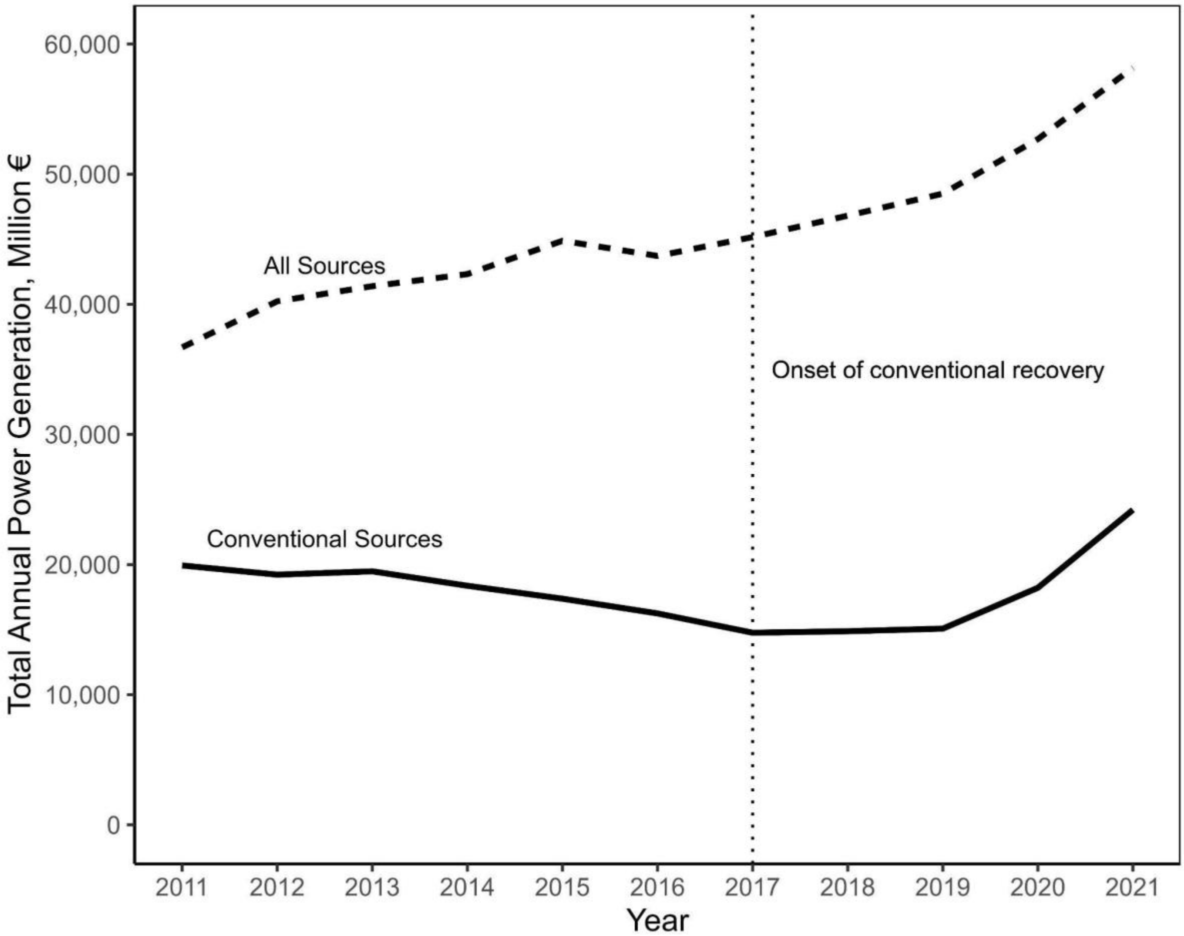
5.2 Uncovering Differential Depth

This section concerns the results of accounting records and physical data analysis. It is an analysis of differential accumulation, deriving Equation 24 - Equation 27, described in Section 3.10.1.2 and Appendix 5. The section examines the suggestion made in Hypothesis 4, according to which, among other measures, dominant CEG firms regain differential accumulation through inflating differential prices, an external depth strategy (see Section 2.2.3).

Figure 35 and Figure 36 show the development of total revenue from annual generation (i.e. total revenue from the sale of electricity generated within the timespan of a year), total market revenue from annual conventional generation, and the share of market revenue from annual conventional generation in the revenue from total annual generation (%).

As Figure 35 and Figure 36 show, following a decade of decline, conventional market revenues began to rise in 2018, concurrently with a steeper rise in total market revenue from annual generation. The same trend is displayed in the share of conventional market revenue, which rose from 31% to 42%, beginning in 2020.

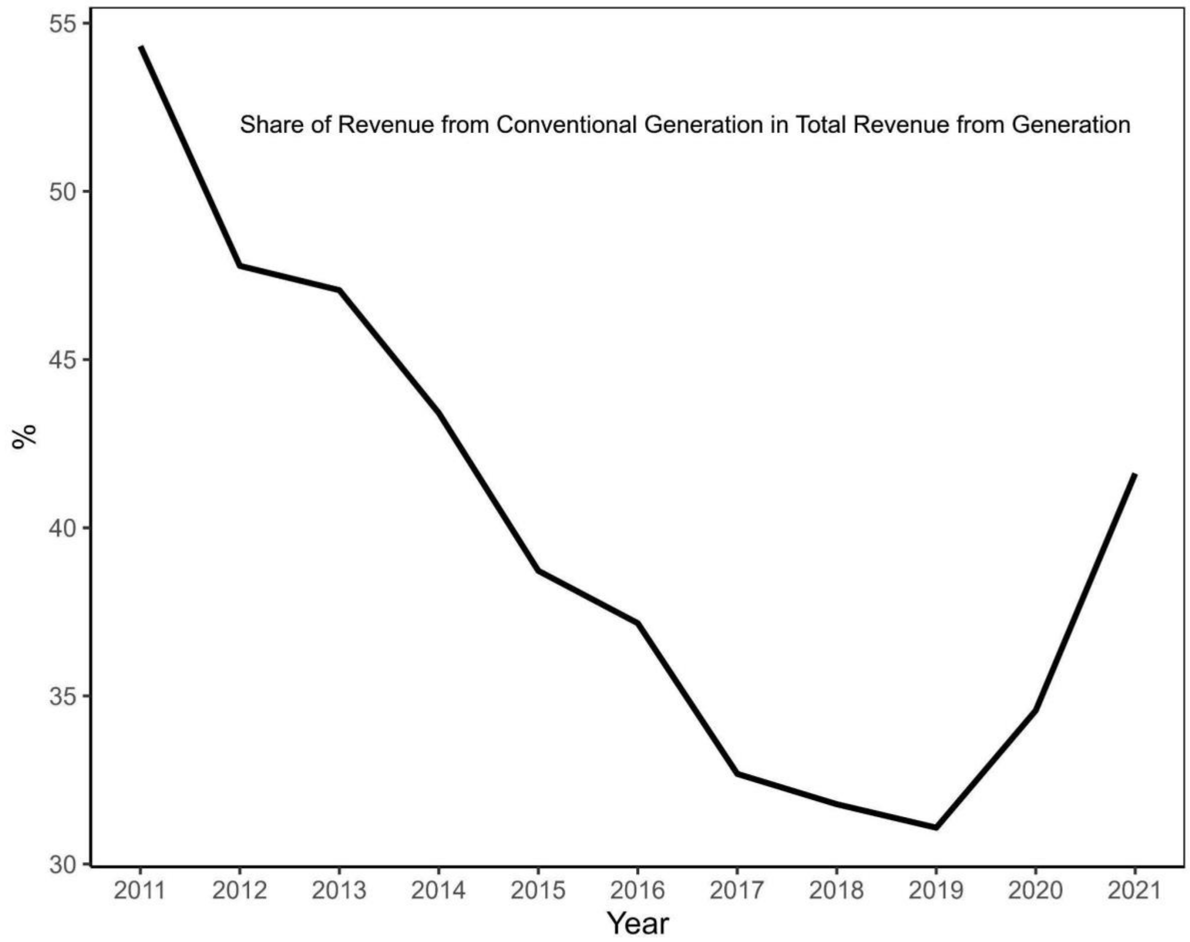
Figure 35: Revenue from Total Annual Electricity Generation and Annual Conventional Electricity Generation, Germany, 2011-2021



Note: Total market revenue from annual generation and total revenue from conventional generation are approximations since separate data on the energy procurement component and the supply component were unavailable for all years.

Sources: Total EEG remuneration and its breakdown: BMWK datasheet "EEG in Zahlen"; Non-household and household electricity consumption: AGEB datasheet "Stormverbrauch nach Kundengruppen"; For an explanation on how the average non-household energy procurement and supply component was estimated see Appendix 5.5.

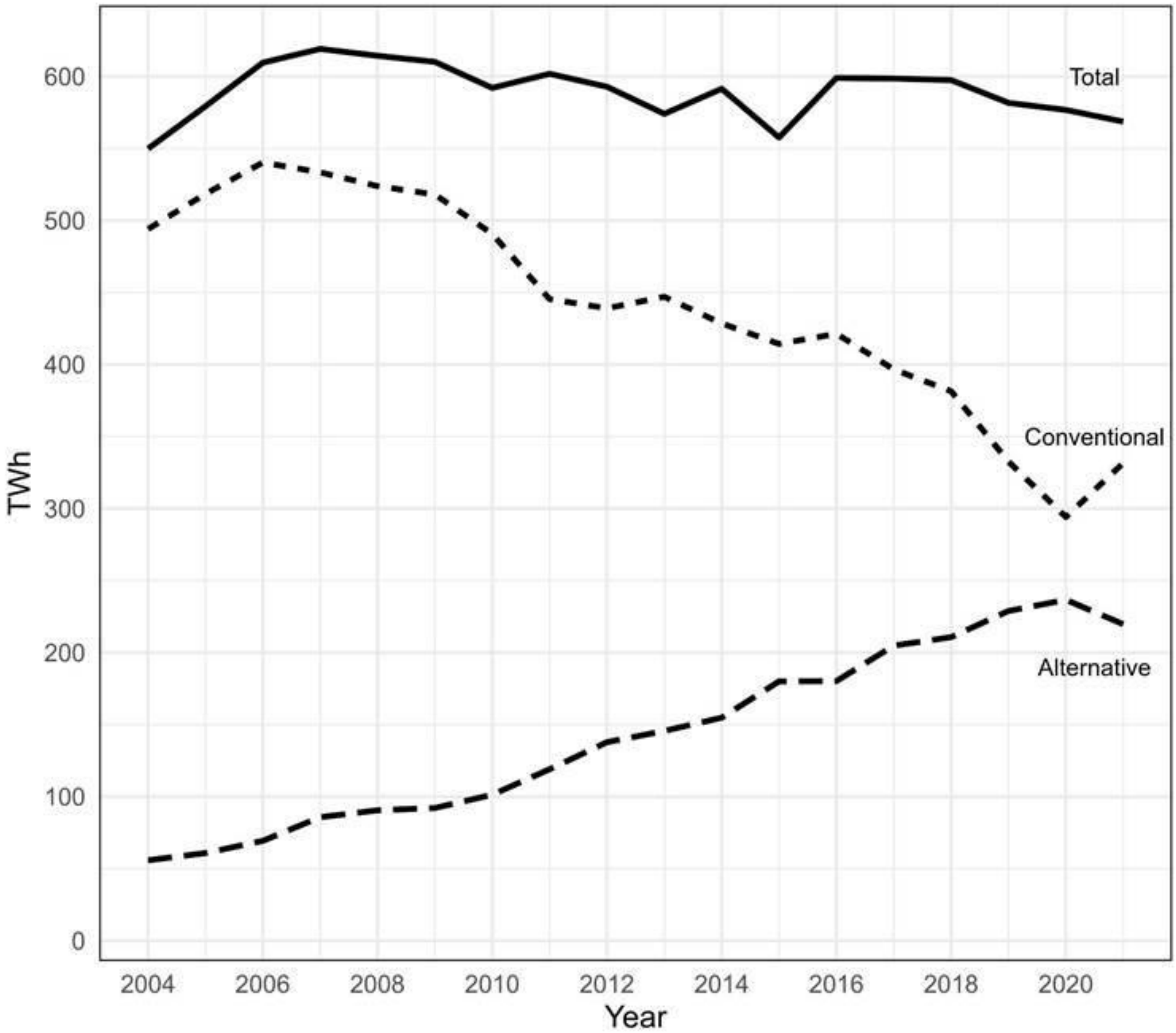
Figure 36: Share of revenue from conventional electricity generation in the revenue from total electricity generation, Germany, 2011-2021



Sources: see Figure 35.

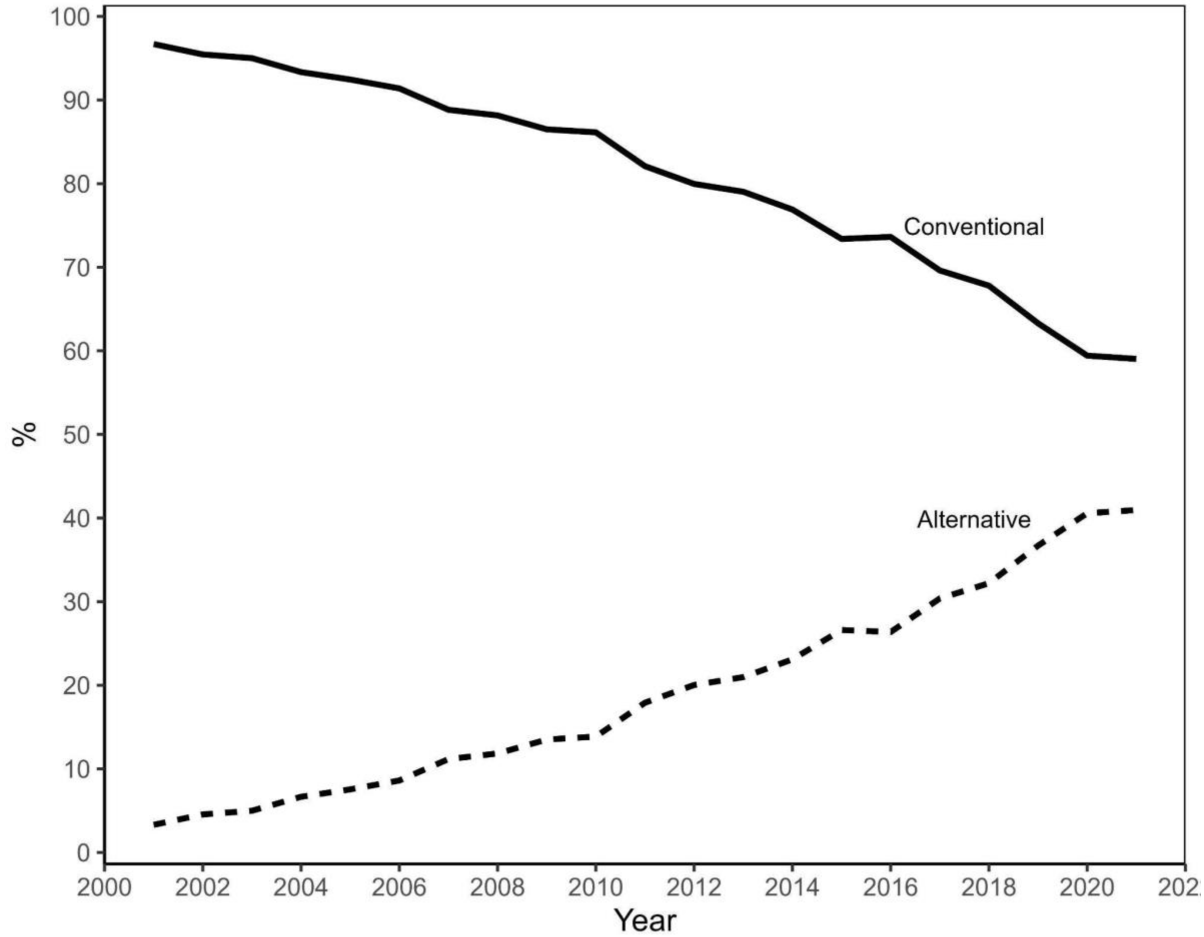
As seen in Figure 37 and Figure 38, during these years, CEG was consistently losing market share, as it kept decreasing in absolute and relative terms in favour of increased RES production.

Figure 37: Total Net Electricity Generation by electricity generation category, Germany, 2004-2021



Sources: TNG by fuel type: AGEB Datasheet "Stromerzeugung nach Energieträgern (Strommix) von 1990 bis 2022 (in TWh) Deutschland insgesamt".

Figure 38: Shares in Total Net Electricity Generation by electricity generation category, Germany, 2001-2021



Sources: see Figure 37.

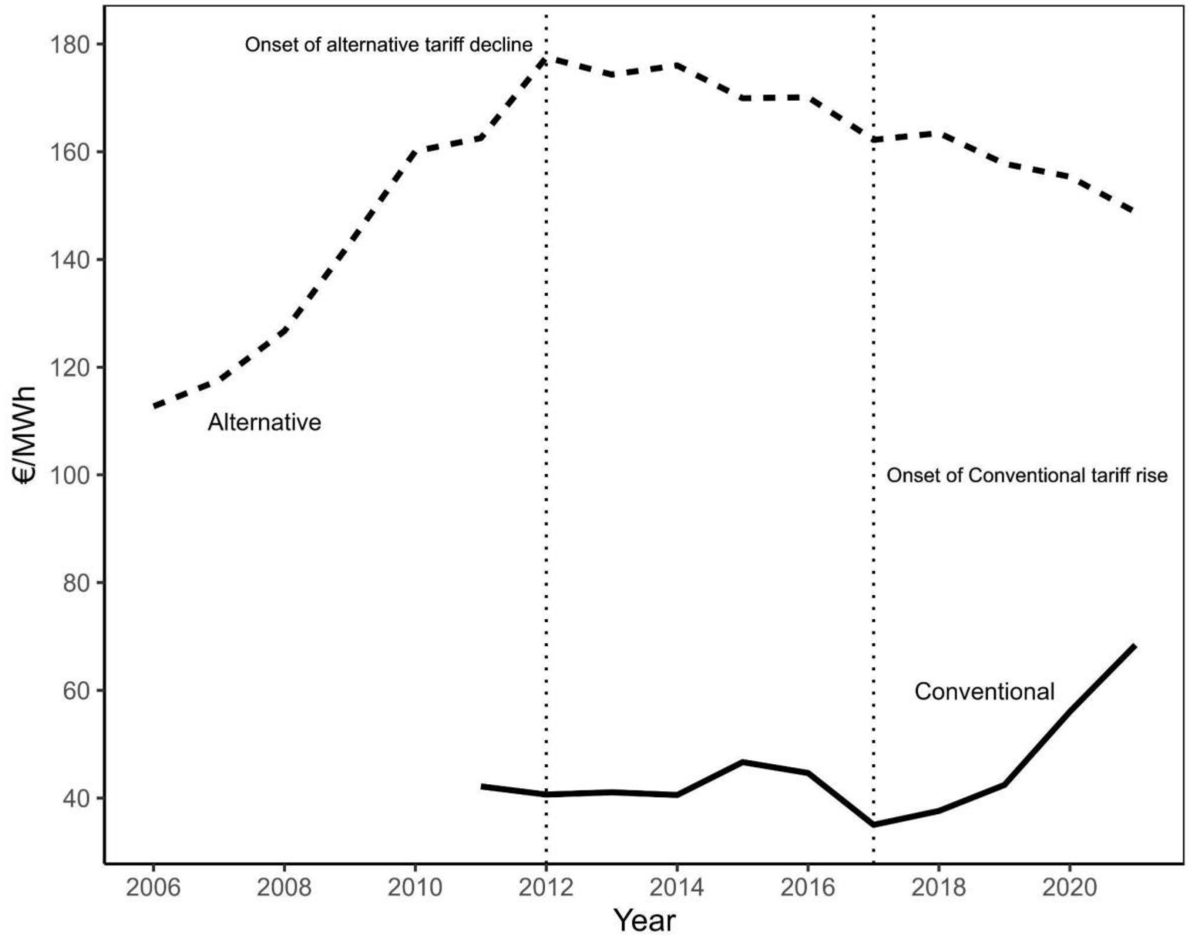
Apparently, CEG firms were recovering **despite** accelerated output loss. I turned to differential depth measures to analyse the source of this recovery.

Figure 39 shows the results of conventional and alternative tariff analysis, based on Equation 24 and Equation 25 (see Section 3.10.1.2 and Appendix 5). It is an expression of revenue per energy unit.

As can be seen, following a period of stagnation, revenue per conventional MWh began to rise in 2018, soaring in 2020, and reaching 70 €/MWh in 2021, 1.7 times the average conventional tariff for 2011-2018. Meanwhile, following a period of growth that lasted from 2006-2012 (2012 is 60% higher than 2006), the Alternative tariff began a secular decline, dropping from

177.5 €/MWh in 2012 to 148.8 €/MWh in 2021.[123] This finding implies that, despite losing differential breadth, CEG firms succeeded in increasing their differential depth (price per energy unit) to a degree overriding their loss of output share.

Figure 39: Conventional and Alternative Revenue per Unit of Energy Generation, Germany, 2006-2021

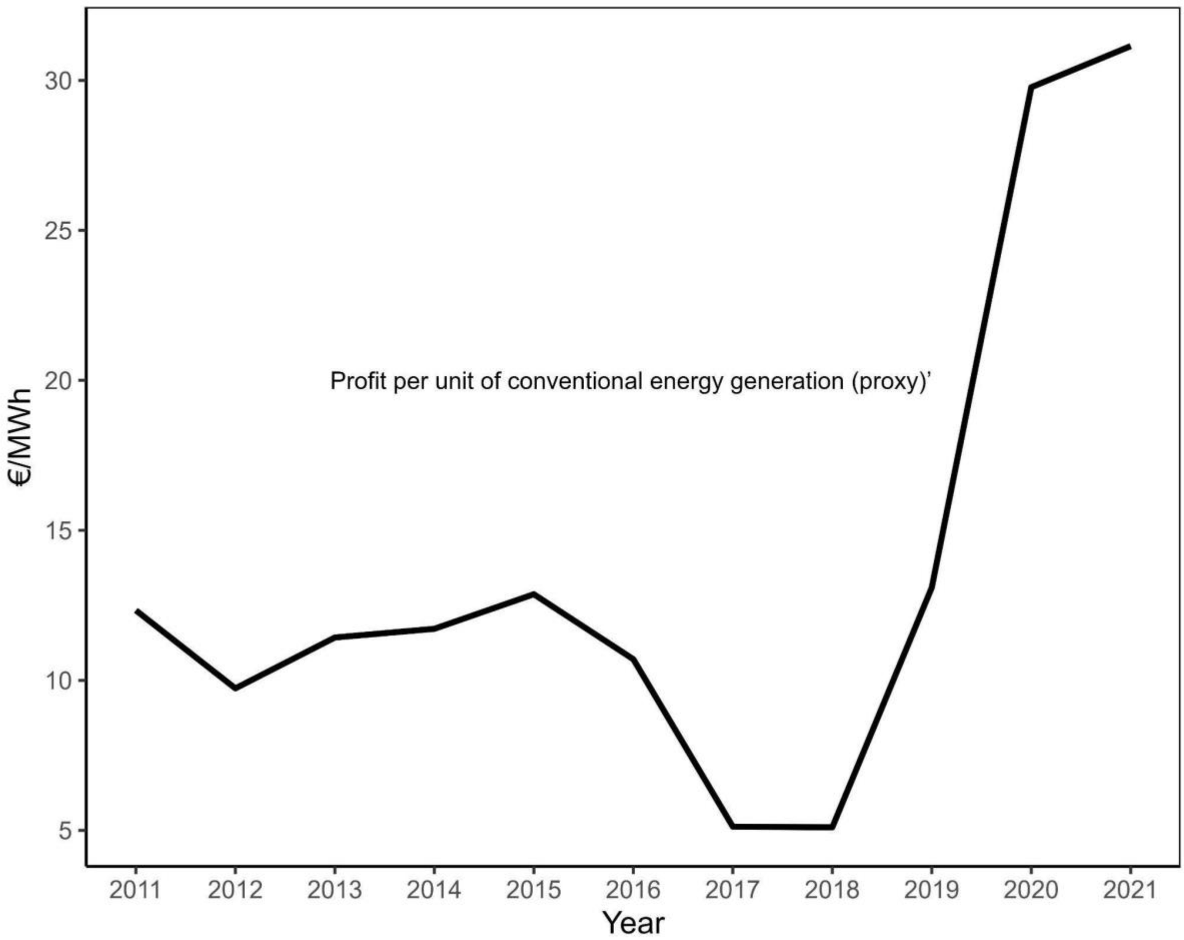


Note: Calculations are based on the conventional and alternative tariff tools presented in Section 3.10.1.2 and Appendix 5, Please note that generation market revenue is an approximation, as separate data on the energy procurement component and the supply component were unavailable for all years.
Sources: Total EEG remuneration and its breakdown and EEG eligible total net generation: see Figure 35; AGEB datasheet "Stormerzeugung nach Energieträgern (Strommix) von 1990 bis 2022 (in TWh) Deutschland insgesamt" for total net generation; Non-household and household electricity consumption: see Figure 35; for an explanation on how the average non-household energy procurement component was estimated see Appendix 5.5.

[123] The alternative tariff reflects market revenue as well as subsidy revenue, so that its level is considerably higher than the conventional tariff.

Figure 40 presents profit per generation, based on Equation 27 (see Section 3.10.1.2 and Appendix 5). This figure shows that even when subtracting fuel costs, the trend remains similar. Hence, the rising conventional tariff is not a case of "cost pushing" due to fuel price rises. Rather, CEG firms succeeded in sustaining high profit margins despite fuel cost fluctuations.

Figure 40: Profit per Unit of Conventional Energy Generation (proxy), Germany, 2011-2021



Note: Calculations are based on the Profit per Energy tool presented in Section 3.10.1.2 and Appendix 5.
Sources: Total EEG remuneration and its breakdown and EEG eligible total net generation, Total net generation, and Non-household and household electricity consumption: see Figure 35; for an explanation on how the average non-household energy procurement component was estimated see Appendix 5.5; BDEW datasheet "enpr.xlsx" for fuel prices in electricity generation; AGEB datasheet "Auswertungstabellen zur Energiebilanz 1990 bis 2021" for fuel use in electricity generation.

The results indicate rising differential depth in favour of CEG firms. This finding supported Hypothesis 4 and set me off researching the mechanisms behind it.[124]

5.3 Conventional Concentration

This section showcases the results of accounting records analysis, based on the conventional concentration tool - Equation 30, as introduced in Section 3.10.1.2 and in Appendix 5. The analysis presented forthwith also relates to a suggestion made in Hypothesis 4, according to which dominant CEG firms would strive to centralize ownership over diminishing conventional installed capacities in their hand, as part of their effort to control and shape differential prices and secure their future stream of income.

Up to this point, my findings traced CEG and AEG dynamics. But what of the relations between dominant and non-dominant actors?

Figure 41 shows the share of big firms' revenue in total electricity sales, alongside the share of CEG in total electricity sales. I consider the 'big firm' category as a reasonable proxy for dominant firms' revenue trends in the generation segment.[125]

It seems that the findings support Hypothesis 4. While big firms and CEG shares of total electricity sales generally display a similar trend, they tend to approach each other over the examined period. Even more importantly, in 2017-21, when both shares in total sales began to rise, their levels completely converged. This finding implies that although dominant firms' share of the generation segment declined, as nuclear and coal capacity (which they dominate)

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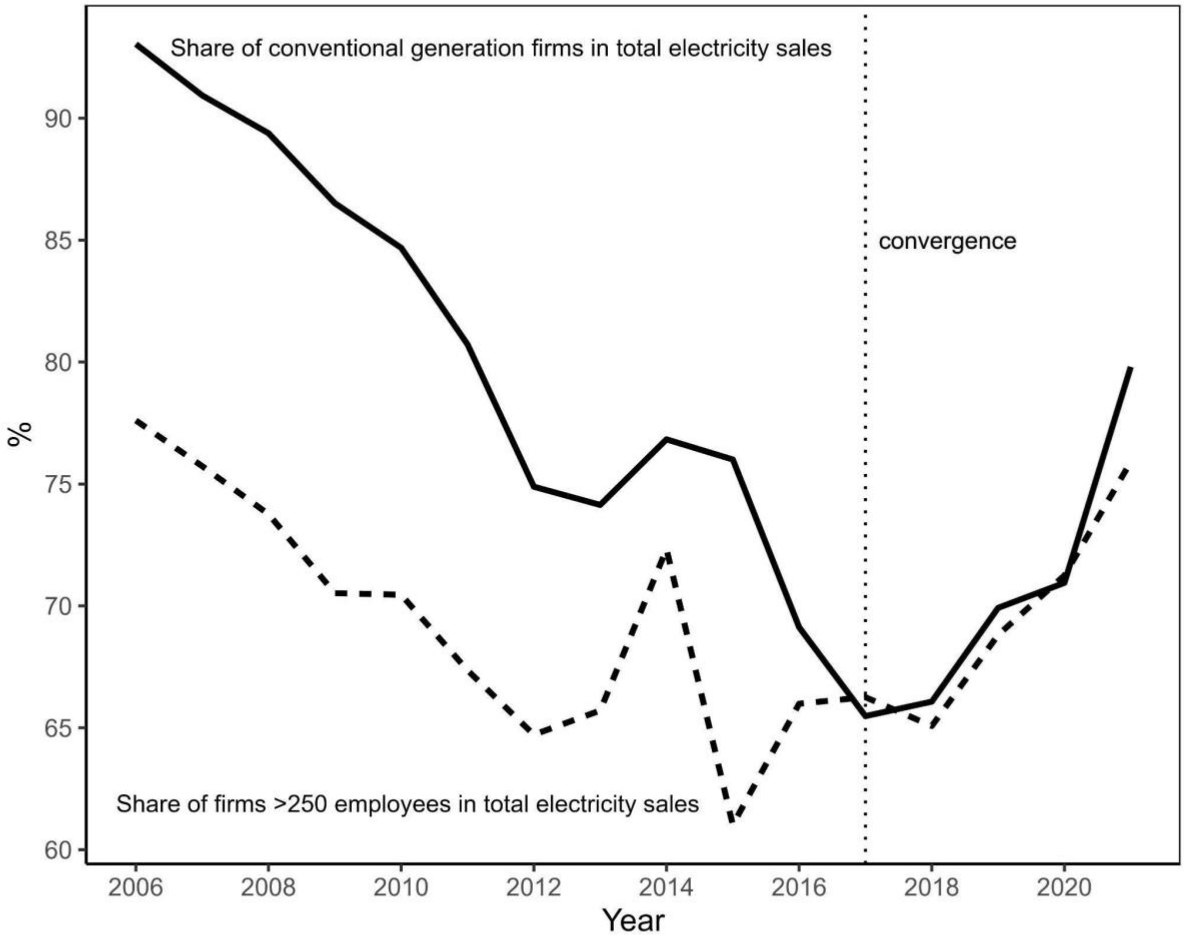
[124] To my knowledge, this is a novel finding. Most analyses of prices in the German generation segment are based on wholesale power exchange data, which aggregates transaction values regardless of source, and only in part (omitting over-the-counter trading). It was necessary to break down this aggregated market front to expose a recent and ongoing differential depth process.

[125] This category consists of an average of 60 firms between 2010-2021, while the number of electricity generators during this period lies between 33,000-70,000. This core of big firms (which I assume control mainly conventional generation) includes dominant firms which currently control about ⅔ of conventional production (see Table 3 and Table 4 Section 3.7.2.3). Therefore, it can be considered as a reasonable proxy for dominant firms' revenue trends in the generation segment.

were decommissioned, beginning in 2017 they succeeded in concentrating conventional sales in their hands. This concentrated ownership group stands behind the conventional differential depth process starting in 2018 and is the main beneficiary of it.

Figure 41: Share of Conventional Electricity Generation and Big Firms in Total Electricity Sales, Germany, 2006-2021



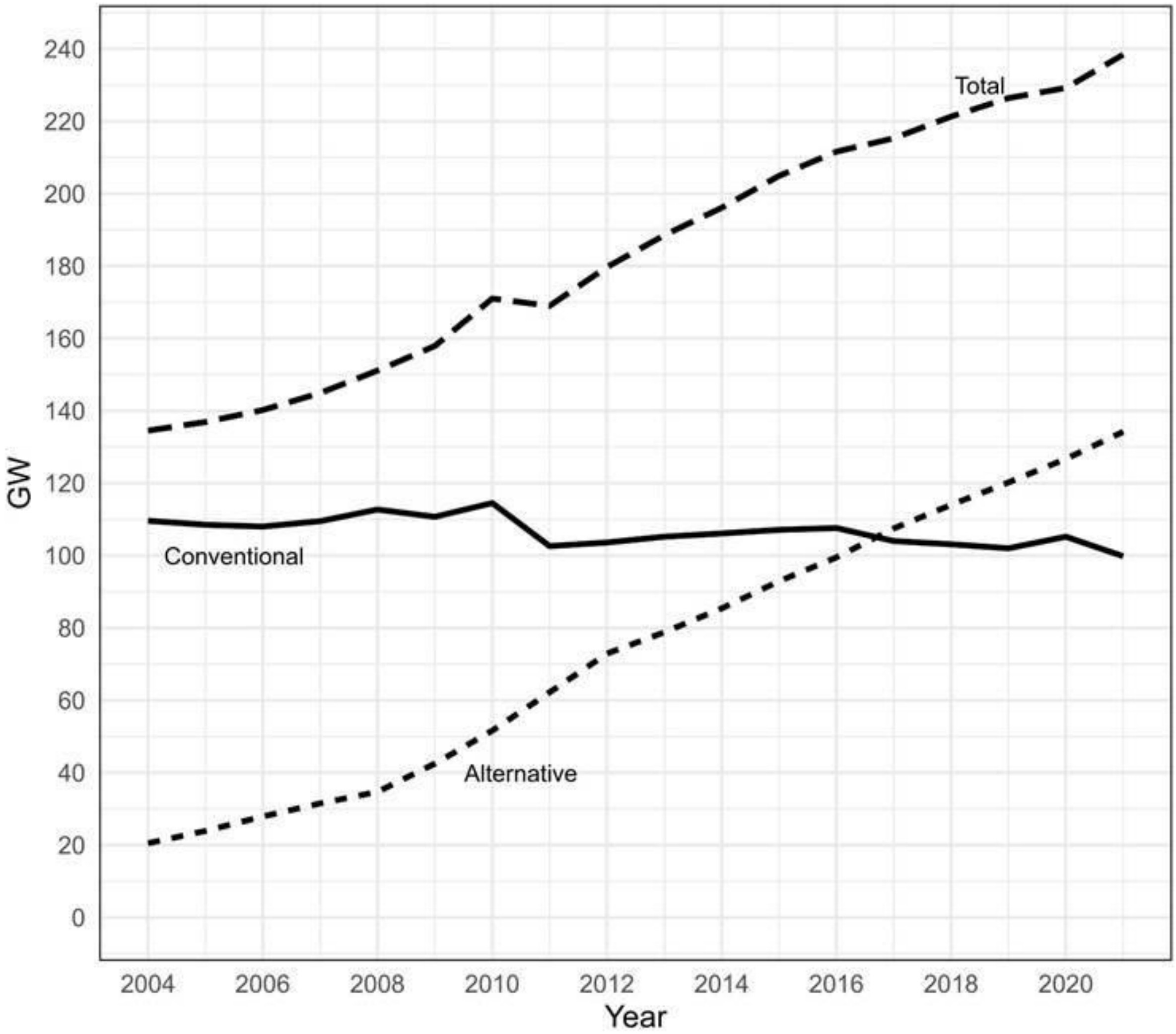
Note: Total electricity sales refer to all revenue from electricity-generation-related business activity, including forwards and futures which are recorded on income statements. Data for big firms' revenue was missing in 2016-2017. For details on how I estimated these two values see Appendix 5.5. Sources: Total sales from electricity generation (Elektrizitätserzeuging) by company size 2006-2021: DeStatis data series "Destatis_749196_E12_URS_RE_Abschnitt_E_4Steller_BJ06-21".

5.4 Revealing the sabotage mechanism.

In this last part, I provide a physical and accounting-records analysis, the first combining data from annual peak hourly load and Conventional Electricity Generation (CEG), while the second examines total electricity sales in relation to annual CEG revenue. Specifically, I look at the ratio of conventional installed capacity to peak load, and the ratio of total electricity sales to revenue from annual CEG (Equation 28 and Equation 29, introduced in Section 3.10.1.2 and Appendix 5). This approach, I claim, sheds light on the power mechanism behind the recovery of dominant CEG firms. Note that conventional generation market revenue includes only revenue from the sale of electricity generated during a respective year, while total electricity sales include forward contracts. The analysis evaluates Hypothesis 5, and the suggestion that when faced with decreasing output shares and increasing uncertainty dominant firms may try to leverage the techno-physical challenges of decarbonization and the resulting systemic dependence on conventional capacity to secure differential accumulation.

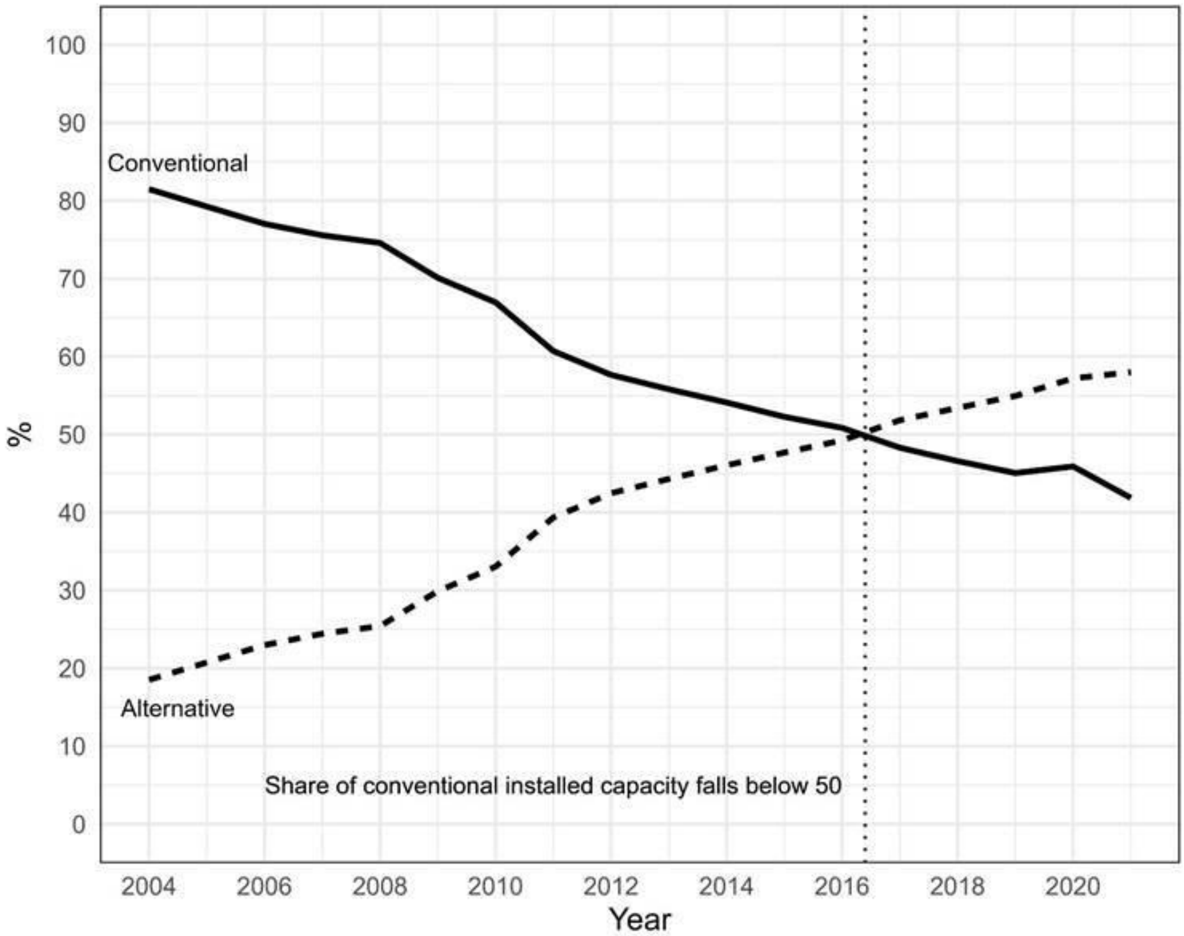
Figure 42 and Figure 43 show the decrease in Conventional Installed Capacity, and its share of the Total Net Installed Nominal Generation Capacity. In 2017, for the first time, the share of conventional installed capacity in the total net installed capacity fell below 50%.

Figure 42: Conventional and alternative installed capacity, Germany, 2004-2021



Sources: Total net installed generation capacity and EEG eligible installed generation capacity were compiled from BnetzA Monitoring Reports 2013-2023.

Figure 43: Share of conventional and alternative installed capacity in total net installed capacity, Germany, 2004-2021



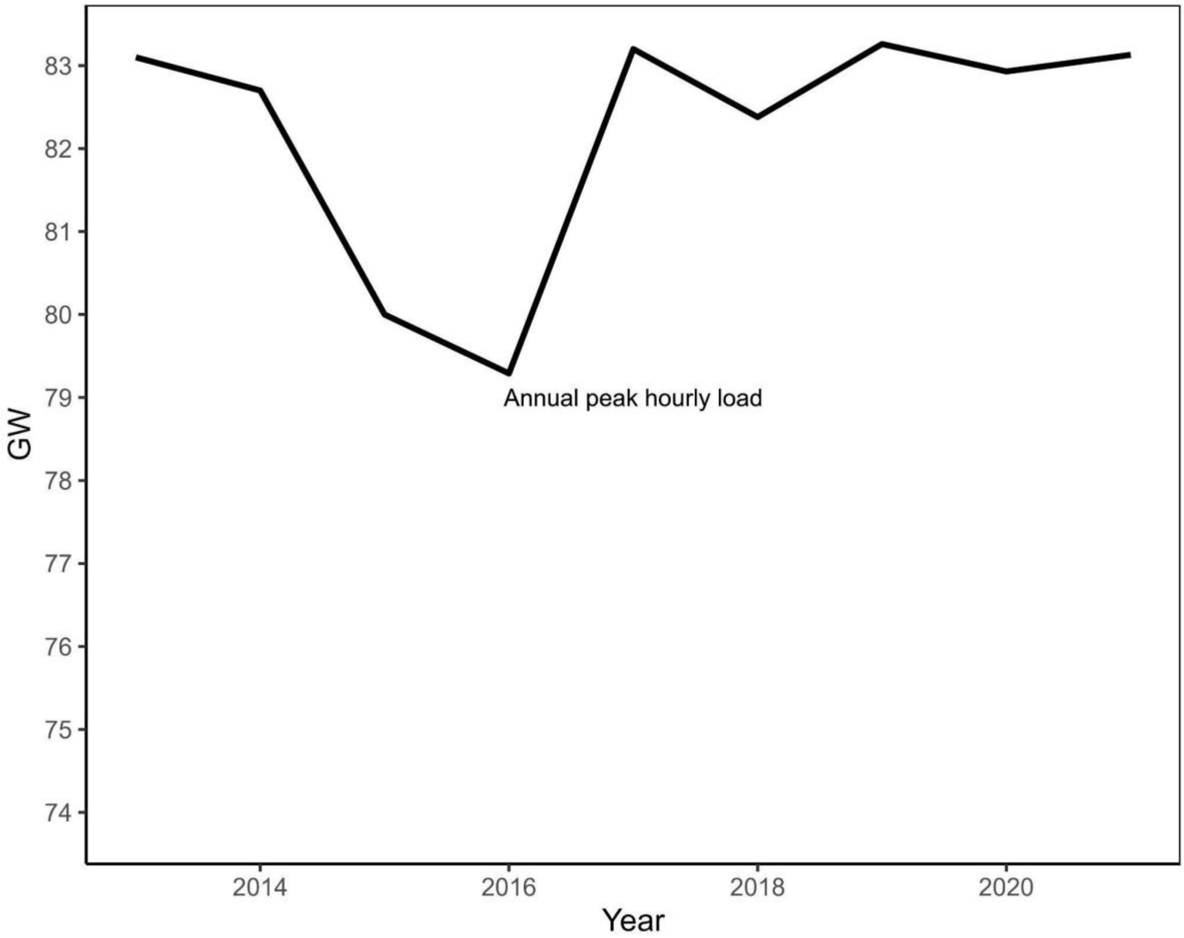
Sources: see Figure 42.

The following figures relate to decreasing conventional installed capacity in the context of securing a reliable electricity supply.

The measure of annual peak hourly load is central to understanding grid reliability, as it sets the maximum energy demand a grid must support by all available generators.

As shown in Figure 44, annual peak hourly load in Germany has remained relatively stable at about 83 GW in recent years.

Figure 44: Annual Peak Hourly Load, Germany, 2013-2021



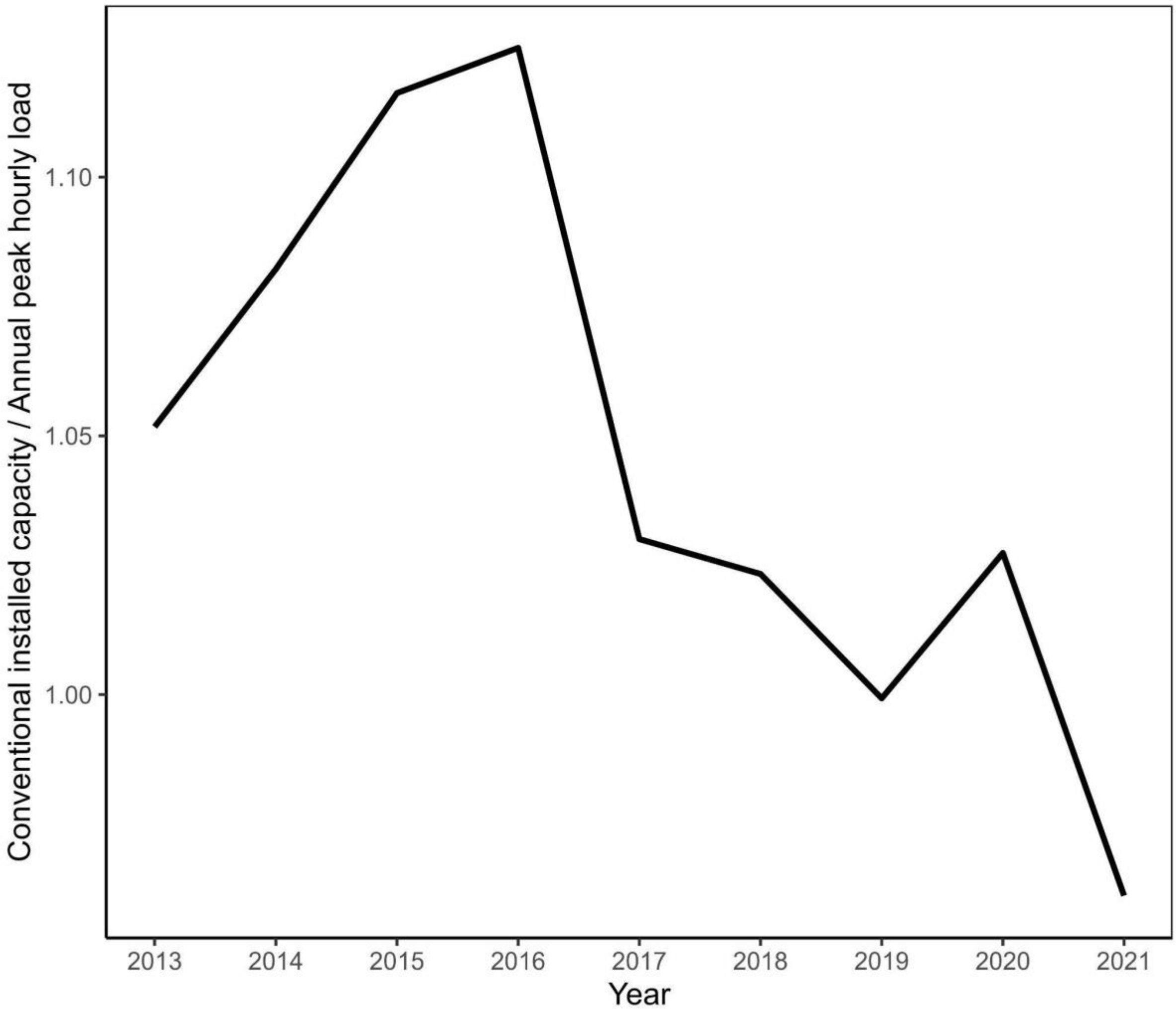
Source: Annual peak hourly load for Germany (monthly data, 2016-2023) was retrieved from Statista, https://www.statista.com/statistics/1342214/peak-hourly-electricity-load-germany-by-month/. Accessed: 30.9.2023.

Figure 45 shows the ratio of Conventional Installed Capacity to Annual Peak Hourly Load. The ratio began to decline in 2017, even going below 1 in 2021.[126] Most importantly, this trend anticipates the level of the conventional tariff: a reduced capacity reserve 'predicts' a higher price level in the short term.[127] This implies that the reduced capacity buffer enables conventional firms greater leverage to increase prices and extract profits. Combined with a

[126] A similar trend of diminishing capacity reserve appears also for non-variable generation in total.
[127] To illustrate, compare decline in Conventional installed capacity / Annual peak hourly load ratio beginning in 2016 (Figure 45) to incline in profit per CEG beginning in 2018 (Figure 40).

growing concentration in the conventional generation segment, these findings indicate an improved ability of dominant firms to coordinate and restrict electricity generation in general.

Figure 45: Ratio of Conventional Installed Capacity to Annual Peak Hourly Load, Germany, 2013-2021



Note: Conventional Installed capacity refers to fossil-fuel and nuclear capacity. Sources: Annual peak hourly load: see Figure 44. Installed conventional capacity was compiled from BnetzA monitoring reports 2013-2022.

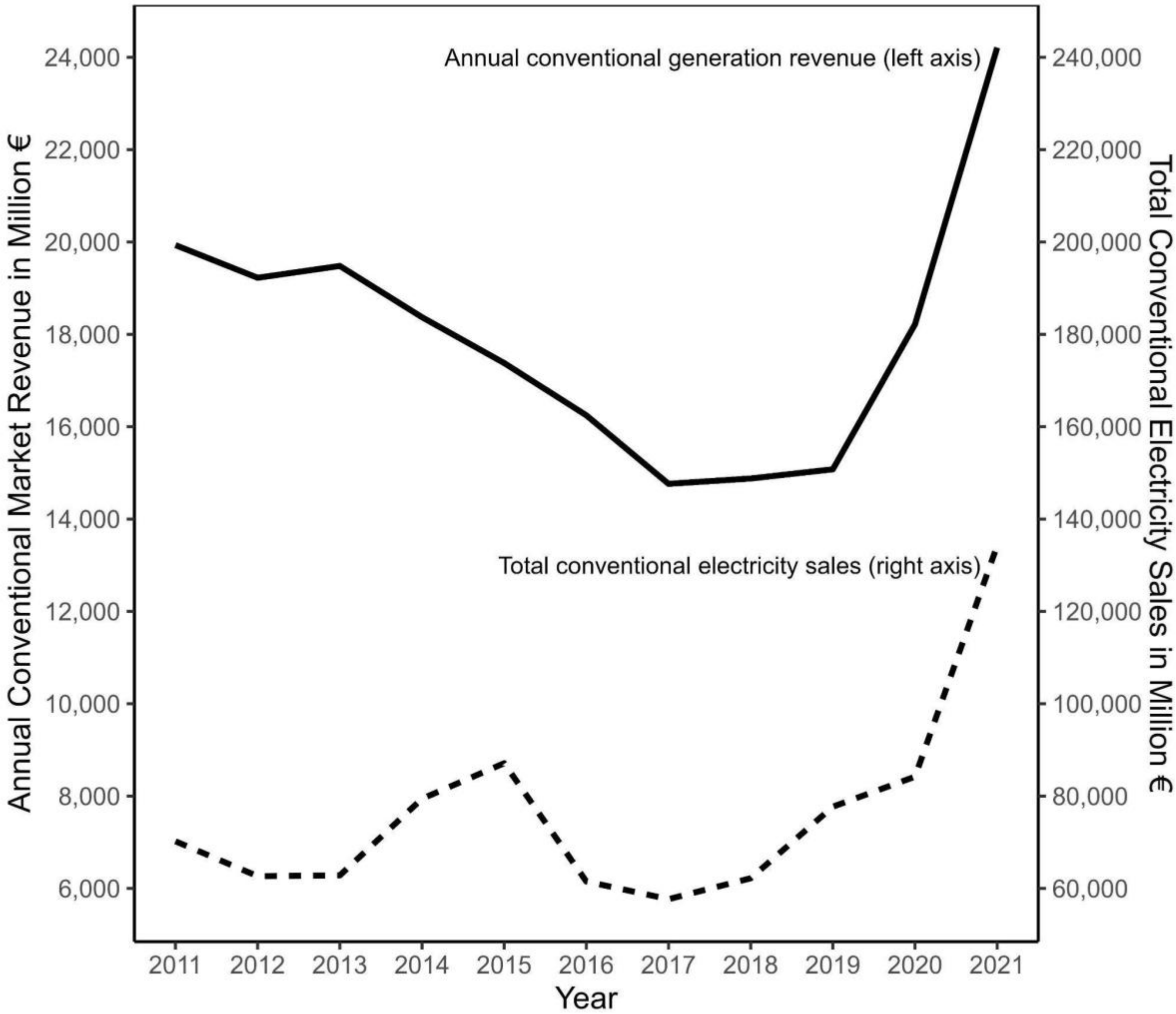
Note that although conventional generators' share in total net generation has declined, their installed capacity is still critical to ensuring reliable supply (see Appendix 9).

The physical data analysis relates even more closely to differential depth, when examined by Equation 29 (introduced in Section 3.10.1.2 and Appendix 5).

Figure 46 and Figure 47 show the development of Total Electricity Sales, revenue from annual electricity generation and their ratio.

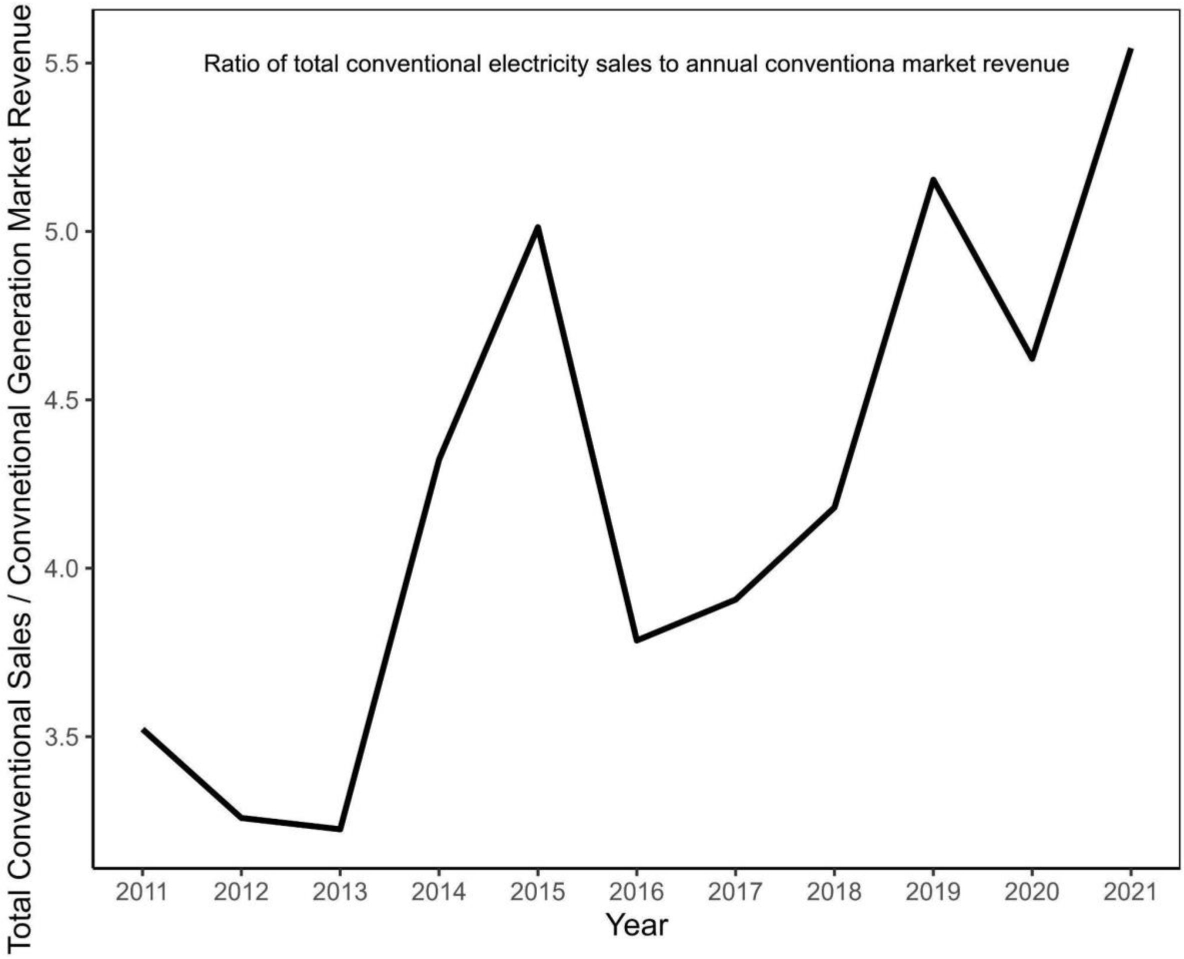
As shown in Figure 46 and Figure 47, the relative magnitudes of conventional total electricity sales and CEG market revenue change dramatically over time. While CEG market revenue displayed a 63% rise between 2017-21, conventional total electricity sales soared by 130%. In 2021, conventional total electricity sales were 5.5 times higher than CEG market revenue. As shown in Figure 48, the ratio movements parallel those of the changing Conventional Installed Capacity / Peak Annual Hourly Load ratio: as the latter fell, the revenue ratio rose to a higher level.

Figure 46: Total Electricity Sales and Annual Electricity Generation Revenue, Germany, 2011-2021



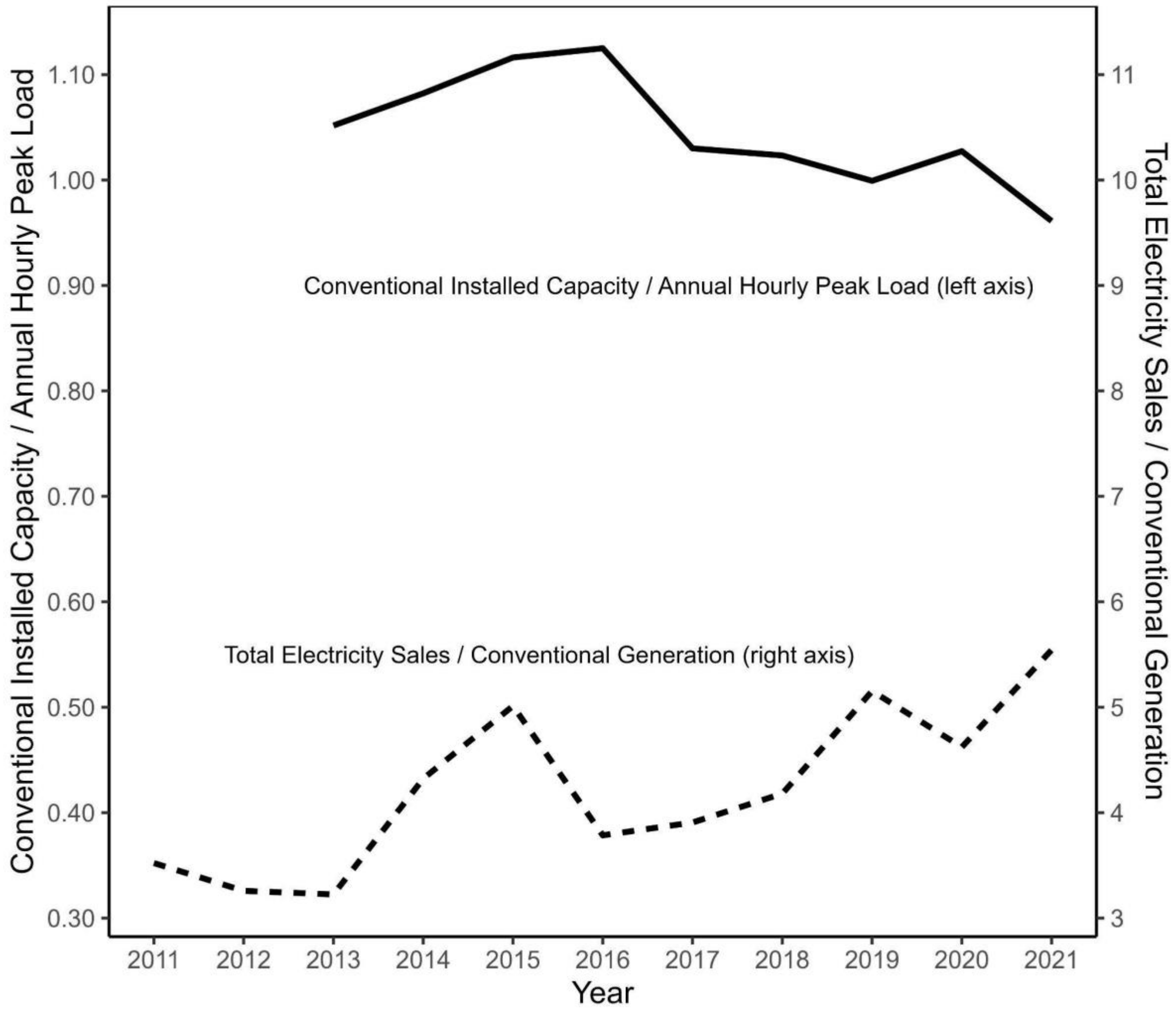
Note: Annual Conventional Electricity Generation is plotted against the left y axis. Total Conventional Electricity Sales is plotted against the right y axis. Total electricity sales refer to all revenue from non-EEG electricity-generation-related business activity, including forwards and futures which are recorded in the income statement. It is calculated by subtracting total EEG remuneration from Total Electricity Sales. See conventional tariff measure, Section 3.10.1.2 and Appendix 5, and note to Figure 39 for explanation of CEG market revenue estimation. Sources: Total sales from electricity generation (Elektrizitätserzeugung) 2006-2021: see Figure 41; Total EEG remuneration and its breakdown: see Figure 39; Non-household and household electricity consumption: see Figure 35; for an explanation on how the average non-household energy procurement and supply component was estimated see Appendix 5.5.

Figure 47: Total Electricity Sales and Annual Electricity Generation Revenue Ratio, Germany, 2011-2021



Sources: see Figure 46.

Figure 48: Comparison of Conventional Installed Capacity / Peak Annual Hourly Load ratio and Total Electricity Sales / Conventional Generation Revenue ratio trends, Germany, 2011-2021



Note: Conventional Installed Capacity / Annual Peak Hourly Load ratio is plotted against the left y axis, Total Electricity Sales / Conventional Generation Revenue ratio is plotted against the right y axis. Sources: Conventional Installed Capacity / Annual Peak Hourly Load: see Figure 45; Total Electricity Sales / Conventional Generation Revenue: see Figure 46.

Appendix 10 demonstrates the similarities between the Total Electricity Sales / Conventional Electricity Generation revenue ratio trends and average EEX Year Future[128] price development trends.

[128] The European Energy Exchange (EEX) is a central European electric power exchange located in Leipzig, Germany.

The findings presented above support Hypothesis 5 and reveal the mechanism behind the rising conventional tariff and the rising differential depth of conventional and dominant firms.

A growing uncertainty of supply (declining conventional capacity combined with increasing variable energy resource penetration) amplified dominant firms' effective threat to "hold back (dispatchable) supply", especially during peak load. These conditions pushed buyers (retailers and industrial customers alike) to sign forward contracts, hedging against perceived future price hikes, and enabling conventional generators to appropriate higher revenues. This manifested in a rising conventional tariff, and a growing income share for dominant firms.

Thus, despite the initial set back, dominant capital has reasserted sectoral control by increasing its threat to reliable power supply. Concentrating their control over the shrinking conventional generation capacity, while variable energy resource penetration expanded, provided dominant firms with the leverage needed to increase differential prices and profits.

5.5 Conclusion

To conclude, the findings presented in this chapter support the claim that dominant capital has reasserted sectoral control by increasing its threat to reliable electricity supply. The analysis as a whole is an exploration of the path-reinforcing dynamics associated with internal depth differential accumulation strategies and increasing ownership concentration described in the analytical perspective (see Section 3.5).

The differential financial recovery of CEG firms began in 2017 (Figure 32 - Figure 34). This recovery was possible *despite* CEG output loss (Figure 37 - Figure 38), through increasing differential depth, which manifested in the rising conventional tariff (Figure 35 - , Figure 39 - Figure 40). The rise in conventional tariff began in 2018 and coincided with a decline in the Conventional Installed Capacity / Annual Peak Hourly Load ratio (Figure 45) due to processes of conventional decommissioning (Figure 42 - Figure 43), which preceded it by a year. I claim that CEG firms leveraged the reduced capacity buffer to increase prices and extract profits. This claim is supported by the findings presented in Figure 46 and Figure 48, which indicate that a growing share of CEG revenue can be attributed to the sale of forward contracts. Anticipating a growing uncertainty of supply, customers are pushed to hedge against future price hikes, enabling CEG firms to appropriate higher revenues. The main beneficiaries are big CEG firms, who succeeded in concentrating CEG sales into their hands (Figure 41).

6. Securing reliable supply: How conventional electricity generation firms strive to lower risks, secure future earnings, and regain their dominant position

This chapter presents and discusses the results of the qualitative analysis of in-depth interviews held with business representatives of the German electricity sector: major conventional electricity generation (CEG) firms, transmission system operator (TSO) firms, and the Bundesverband der Energie-und Wasserwirtschaft (BDEW)[129] (see Section 3.10.2). The analysis pursues issues left open by the quantitative analysis of the German Energiewende case study.

The quantitative analysis of the German case study was left off with an unsolved question: by what means have dominant firms appropriated rising shares of conventional revenue? And what mechanisms lie behind their rising differential tariff?

I used the qualitative analysis of in-depth interviews with electricity sector business representatives to confirm and reinforce quantitative results and their interpretation, shed light where quantitative data was lacking, and also, as will be presented in Section 6.4, to direct us to a further quantitative analysis whose significance surfaced during the qualitative analysis.

[129] The BDEW is the German industrial association representing firms in the energy and waterworks sectors.

The major findings of the interviews' analysis regard the ways in which *strategic* sabotage[130] is inflicted on the transitioning electricity sector and are complementary to the quantitative analysis and its interpretation. They run as follows:

1. Though a shift to investment in RES is inevitable, renewable generation in Germany is not, and will not become, a source of differential profit for dominant CEG firms. This is because renewable generation is harder to control and to monopolize, and thus it is harder both to shape and to secure differential future earnings. Risk[131] is evenly encountered, differential risk reduction is hard to achieve, and earnings are significantly shaped by regulation.
2. The one exception to this state of affairs are offshore wind farms, for which exceedingly high initial investment costs act as a mechanism of exclusion and centralization.
3. In contrast, the field of CEG lends itself more willingly to control and concentration, and hence to capitalization of the systemic dependence on dispatchable backup capacities. Thus, dominant CEG firms engage in a double-sided effort to differentially reduce risk and secure differential earnings. These efforts regard both investment in newly planned and commissioned gas and H2-ready[132] facilities, and the operation of

[130] The term *business sabotage* relates a wide range of business practices which impede and undermine the smooth and wholistic run of industry and are the source of business income. *Strategic sabotage* refers to the measured application of business sabotage, so as to attain differentially high returns on actual and threatened damages to industry, while abstaining from the destruction of the industrial and social fabric on which business depends (Nitzan & Bichler, 2009).

[131] Throughout the interviews, the concept of *risk* features strongly in the reasonings of the CEG firms' representatives. Nevertheless, a slight clarification is necessary, in relation to the concept of *risk*, its interpretation and uses. In using the word *risk*, corporate representatives refer to the narrow meaning of the word found in business jargon, and relating to perceived risks to return on investment, both past and future. In contrast, the significance of *risk* in the CasP approach is wider. Within the capitalization formula *risk* refers to the perceived risks to the ability to shape and control social processes which bear on capitalization, at large (Nitzan & Bichler, 2009). In this sense, when our corporate informants speak of *risk* they are referring at the same time to less than *risk* in the CasP sense, and to more, seeing as they also refer to the ability to shape and secure another element of the capitalization formula - (expected future) earnings.

[132] The term *H2-ready power plants* refers to power plants which are built so that they can be converted to Hydrogen combustion (Bundesregierung, 2024).

existing and decommissioning coal-fired power plants. These efforts take the following form:

A. An effort to reduce "regulatory" risk in the rollout of new gas-fired and H2-ready installations, by imposing the institution of convenient conditions for investment in these lacking dispatchable capacities, which only dominant CEG firms are in a position to carry out. In this way, the risks of investment in dispatchable capacities are significantly reduced in relation to RES generation and infrastructure more generally.
B. An effort to concentrate power and ownership over vital new and existing backup capacities, which fortifies dominant CEG firms' ability to shape the revenue stream extracted from their control. This is achieved by setting differentially high electricity prices for dispatchable generation, using bilateral future contracts.
C. An effort to reduce risks in the operation of coal-fired installations by securing both favourable conditions for decommissioning in case of a fulfilment of the coal-exit, and a profitable position for continued operation, in case it will not be carried out as planned. In this way, the alleged risk of the uncertainty of the planned coal-exit is reduced, and CEG firms can continue operating coal-fired power plants so long as they are still differentially profitable and enjoy the subsidy of sponsored decommissioning when conditions change.

4. To conclude, dominant CEG firms must traverse the thin line of strategic sabotage in the context of the Energiewende - not too much so as to undermine the sociotechnical system of electricity generation, and not too little so as to lose the leverage which affords them differential profits.

6.1 Controlling RES is not a source of differential profit

All dominant CEG firms' representatives whom I interviewed positioned their companies as active, or rather, leading actors, in the *Energiewende*. At the same time, they all stressed their dominant role as the sole securers and providers of flexible backup capacities, alongside their investments in RES.

As Adrian,[133] a senior executive in a major CEG firm described it:

> "We see ourselves as an enabler [of the energy transition, T.L.][134]... apart from supplying intermittent renewable electricity, we also say: 'Okay, this intermittent generation needs partners: reliable capacities', and that's what we also want to supply… So, meeting the demands. This means that there will still be times where there is the famous "Dunkelflaute"[135] where other kinds of power, reliable power capacity are needed... And that's what we want to supply. This backup capacity must be flexible… what is flexible? This means renewable or gas-fired power plants".

Leo, a representative of another firm stated that "we have… a key role, I would say, without overestimating our role, in the *Energiewende*… I think we do very much of the heavy lifting of the *Energiewende*", when referring to the company's investment in thermal backup capacities, renewables, and transmission grids.

When asked about the company's role in the *Energiewende*, Axel, yet another CEG firm representative, referred to the war in Ukraine and explained:

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[133] All names used in this chapter are fictitious and used solely to differentiate one interviewee from another. Appendix 13 contains a list of interviewees, a short description of their positions, and details on the time and place of the interview.

[134] Clarification comments added by the author will henceforth be presented in square brackets, followed by the author's initials – T.L.

[135] In RES generation, the Dunkelflaute (coming from the German words Dunkel - dark, and Flaute - lull) refers to periods of adverse weather conditions for renewable generation (i.e., low solar irradiance and wind speed).

> "We see again the point of… energy security, which is an important issue. And I think one of our roles, as a company, is to be a partner to secure energy supply. And there are still the coal-fired power plants… They're not a business case in the typical way and also in the projections we see that running coal-fired power plants, it's not really profitable at all in the long-term. And that's why we are developing… gas-fired H2-ready power plants. They are… our module for energy security".

Adrian stressed that while the firm sees the "increase in renewable power generation as a clear trend, not being reversible… what we have to cope with is the residual load"[136] and "there we are engaged in upcoming investments".

Though all interviewed CEG representatives described their commitment to investing in renewable capacities, it was also made clear that these projects are considered a lesser investment (in scale as well as in expected earnings), while the heavier, and more profitable investments are in dispatchable back-up capacities.

In referring to the company's future, Axel stated:

> "We are a lignite-based[137] company. And lignite has the highest greenhouse gas emissions in electricity production in Germany, perhaps worldwide… We know that our lignite business is ending. And so, we're actually in transformation".

But in describing this transformation he makes clear that though investing in RES is part of the process, CEG firms' business focus is elsewhere. RES projects, he tells us "are not as huge [in

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[136] The term *residual load* refers to the difference between demand and RES generation (Treib & Thess, 2020). Thus, Gunther is referring to flexible generation capacities, predominantly gas and H2-ready power plants.

[137] Lignite, also known as brown-coal, is a type of soft, brownish-black coal. Germany has been the largest lignite producer since the beginning of industrial lignite production (Huy, et al., 2016: 37).

comparison to thermal generation plants, T.L.]. Every electricity company that wants to transform invests in wind parks and solar parks, but those are smaller investments".

Why is investment in RES capacities, though inevitable, considered less significant, from a business perspective? The following content analysis supports the conclusions drawn from the quantitative analysis: Because it is less profitable, and almost impossible to control and exclude others from, under the given circumstances in Germany.[138]

Axel goes on to explain: "It's not the end of renewable support and the… expansion of renewable capacities. But naturally, if you are very optimistic that only a few hours with negative prices will occur, and perhaps you produce at a loss in the long run… your margins will be low". CasP theory suggests that differentially low profit margins are fatal to differential capitalization, for which current earnings play a central role in discounting the present value of expected future earnings. Considering the expected decreases and subsequent relinquishment of RES subsidies,[139] even large CEG firms find RES generation un-(differentially) profitable. As Axel explains:

> "Nobody knows, but I expect that the market will react… and everybody will calculate that perhaps if you have a PV that is erected in the south direction, only in half of the hours you have, in the long run, prices above zero. And in summer times, you can more or less forget about receiving that and then it's better to use a direction of east to west so you [generate, T.L.] more in these early and late hours where you probably have positive prices or you combine it with storage… The rest [of generated RES electricity, T.L.] you will have to bid in tenders

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[138] These conditions include the techno-physical features of the majority of RES, namely variability and uncertainty, which make them harder to control and imply a reliance on environmental conditions which *all* RES generators are jointly susceptible to. In addition, EEG legislation and related regulation mandates the sale of RES electricity, as well as the connection of all and every new RES installation to the grid, making 'withholding' irrelevant. For further details see Section 3.7.2.1.

[139] The waiving of renewable subsidies includes the elimination of the FinT, the phasing out of market premium mechanisms, and the planned shift to double sided CfDs (see Footnote 140) in RES generated electricity marketing (Leiren & Reimer, 2018). For further information, see Section 3.7.2.1.

> where you have these one-sided CFD, and in the long run it will probably be two-sided CFD tenders,[140] let's say [by, T.L.] 2027 perhaps".

Adrian, a senior executive in a dominant CEG firm, describes the firm's strategy of achieving scale and dominance in RES generation by centralization and exclusion: "our strategy is to win as many tenders as possible, get hold of each and every renewable project we can get". Yet even for dominant firms, achieving control of RES generation capacities is difficult, for technical and spatial, as well as regulatory, reasons:

A. In the first place, achieving dominance in onshore RES generation requires the control of large areas of land as is expressed in the following quotes, from Adrian and Axel, representatives of two different companies: "For onshore wind and solar the main restriction is to get space, to get areas where we can build, where you get permits and approval", and "The problem is that we have limitations in the size of such PV plants,[141] actually, it's 50 MW… for solar parks, and due to the reason that we have such concentrated lignite mine areas".

B. Dominant CEG firms, which are no longer exclusively national and have a global reach, may find the spatio-physical conditions of RES generation in Germany to be unfavourable, and choose to develop RES projects elsewhere. Marius, a former BDEW employee, expressed the concern that RES capacities in Germany will suffer relative profitability losses as a more integrated European power grid evolves, and RES capacities are built in other European countries with better conditions for RES generation. "What is certain," he states, "is that Germany is set to lose competitiveness in the new system, simply due to the fact that the conditions for renewables in Germany

[140] While one sided Contracts of Differences (CfDs) ensure the reimbursement of electricity generators in case prices fall below a certain level, two sided CfDs also stipulates that electricity suppliers must reimburse purchasers in case prices rise above a certain level (Khodadadi & Poudineh, 2024).

[141] Axel is referring to subsidized RES capacities available in the auction system.

aren't as good as [in, T.L.] many other countries… others will catch up, and they will even surpass”. Hence, as Stephan, another BDEW employee, explains, dominant German CEG firms are directing significant portions of their investment in RES to projects outside of Germany: “They have a more global view on the energy transition which makes them also more sensitive to the financing conditions. So, they say: well, okay, I have three options,[142] and if Germany is not attractive, I'm not investing”.

C. the phasing out of government subsidies for renewables (see Footnote 139 and Section 3.7.2.1) is considered problematic. It is not the shift to the auctions system which troubles dominant CEG firms, who are in fact big enough to gain from their favourable positions in auctions, but the planned regulation and restriction of profits embodied in a such policies as the introduction of double-sided CfDs (see Footnote 140) and revenue caps. As Leo, a representative of a dominant CEG firm puts it:

> “We were a little bit opposed to the introduction of two-sided CfDs, as now required by the European Union. You might say that it will reduce risk to have a two-sided CfD… and that's true, but we can handle market risks… On the other hand… we have to be very much aware of the distortive effects of two-sided CfDs, which do not occur with one-sided CfDs… So, we were not concerned with the introduction of auctions. We are a bit more concerned, especially our trading department, with the introduction of two-sided CfDs, to be honest”.

He continued to explain that “investors will not invest [in RES, expecting, T.L.] scarcity prices anymore”,[143] because while exceptionally high prices may “occur… the scarcity revenues will

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[142] Stephan is referring to a theoretical set of three potential RES investment projects, in different locations throughout Europe.

[143] In *scarcity prices* Leo is referring to abnormally high prices which occur during periods of shortage in operating reserves, temporarily raising prices above market bids (Helman, et al., 2010).

be taken away from them". Leo defined this as a "market signal", with regards to investment in RES capacities:

> "The more severe result [of high electricity prices, T.L.] was the public intervention by implementing the revenue cap system, albeit a transitory one… which frustrated some renewables investments because renewables were particularly hard hit when they were market-based… The political tolerance towards prices was tested in that period, and what we saw was that in the long run… politicians in the European Union are not prepared to accept prices above, let's say, 180 euros per MWh".

D. Finally, and perhaps most importantly, RES generation is not differentially profitable because of its reliance on weather conditions. The abundance of installed RES capacity relative to demand during favourable generation conditions makes it hard to control, manipulate, and monopolize. As Axel explains:

> "Then we have a huge discussion about paying at negative prices.[144] You see, with such an overcapacity of solar and wind the prices go down if the wind is blowing, if the sun is shining, and that leads to very low and negative prices. Old installations will still receive the market premium, but newer ones have limitations".

Hence, without subsidies, RES generation remains risky and unprofitable:

> "You can build [large RES installations] on your own, but then you have the problem that the market values… are not high due to the reason that we have strong overcapacities… the maximum load in summer is around 60 GW, but we

[144] In the context of electricity trading, negative prices occur on wholesale electricity markets when electricity generation exceeds demand (e.g., during peak RES generation periods) to the extent that generators are willing to pay for the offtake of electricity they generated (Biber et al., 2022).

> already have 90 GW PV installed… So, you can see that PV is destroying its own market prices, and this makes it complicated to build without subsidies".

He concludes bluntly: "The problem that I personally see is that we are more or less used to operating only if we receive subsidies".

Marius, a former BDEW employee, described the apparently still unruly RES development trends in Germany. The description is far from that of an industry under the business control of a small number of dominant firms:

> "There are a lot of warning voices now that we have to sort of decelerate [RES capacity construction, T.L.] a little bit. because many thought we are good on track with our renewables plans… But actually they [government, T.L.] wanted a double amount of wind and a lot less solar, and solar constitutes a big problem, because, I would even dare to say, most of the installations cannot immediately be connected to the grid and still the consumer has to pay for them".

The expressions presented above are in line with the quantitative findings, which show that while RES penetration initially destabilized CEG firms, these started to recover in terms of differential accumulation during the second half of the second decade of the 21st century. It also sheds light on the MaStR database analysis results, which show a decline in RES penetration during this period, and combined trends of spatial and ownership centralization in RES development (Appendix 11).

The difference between large CEG firms' relative confidence in conventional generation in comparison to RES was expressed by Adrian, a senior executive of a dominant CEG firm, when talking of the company's risk perception: "The other issue is that the commitment of politics to the energy transition has to prevail. We are still able to run conventional power generation; that's not a problem. However, we are heavily invested in renewables". The entry barriers to investment in RES, he continues to explain, are very low: "at least investment costs for renewable capacities are, thanks to China, very low", thus, the risk to investment in the narrow sense, is small. On the other hand, the ability to retain control over the social process as a whole is extremely limited in the case of RES generation. Or in the neoliberal jargon of corporate representatives such as Axel, the problem is producing a "good strategy… so that all the things that are needed come at efficient prices… the grid expansion, the backup capacity… and to avoid that markets become tight, especially on the producers' side, also… for the TSOs, which can make energy transitions very expensive",[145] that is to say, to have *strategic* sabotage. Not too much so as to raise system costs in an unsustainable, disruptive way, and not too little, so as to disable differential profits.

These findings support and develop the quantitative analysis results and their interpretation, which suggest that dominant CEG firms continue to rely on CEGs as the source of differential profit, even as they engage in RES development. This is due to the centrality of generation *control*, rather than output quantity, to shaping differential returns, and the techno-physical and regulatory factors which render variable electricity generation harder to control. The content analysis of interviews with German electricity sector business representatives sheds light on the specific features of RES relative resistance to centralized control and exclusion in the context of the German *Energiewende*. It also deepens our understanding of the prevailing power of dominant CEG firms in Germany, despite decarbonization processes, the ways in which CEG firms might use rising *Energiewende* expenses and public unrest to shape the process and their flow of future earnings, and the ways in which changing business strategies shape the German energy transition pathway.

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[145] Axel is referring here to the concern, voiced by many in the German electricity sector, that the high investment expenses required to connect increasing RES penetration in general, and offshore wind in particular, and to secure reliable electricity supply will drive electricity prices up in an unsustainable manner. These expenses include significant, and currently insufficient, investment in costly transmission grid expansions, as well as in expensive flexible back-up capacities and their connection, which are ultimately rolled on to end-customers via the electricity tariff. In market tightness, Axel is referring to a phenomenon which might occur when the supply of physical goods is constrained in relation to demand, enabling producers to set higher prices.

6.1.1 Offshore wind projects are an excludable exception

The previous section presented the claim that RES are harder to control in the context of the German *Energiewende* and therefore dominant CEG firms continue to rely primarily on the control and centralization of CEG to achieve differential capitalization. This sub section will concentrate on offshore wind, which are an exception to this rule. The section demonstrates the centrality of generation control to differential accumulation by showing that when this is achievable is RES, dominant capital strives to appropriate these generation capacities. In addition, the shift of emphasis from decentralized onshore wind and PV installations to centralized offshore wind projects shapes the *Energiewende* trajectory in several ways.

Business control over onshore RES generation in Germany is harder to achieve partly because, as Axel, a large CEG firm representative, remarks, its ownership structure is, as of yet, “very diverse”. He goes on to elaborate: “You have a lot of institutional investors, a lot of municipal electricity companies, a lot of normal, bigger electricity companies that own solar parks and wind parks, onshore at least”. In contrast, “Offshore, the market is more concentrated… and now taken over by the big oil companies”. Here, Axel is referring to big-five oil companies BP and Total Energies winning tenders for large offshore wind development projects within Germany’s national maritime boundaries in the German bight (North Sea) (For further details see Section 7.1).

Considered highly profitable, and requiring high initial investments and ongoing maintenance, only dominant CEG firms can consider entering the field of offshore wind generation. As Gunter, a representative of one large, but not dominant, CEG firm explains: “We are not going into offshore wind because… we are too small for the amount of investments necessary compared to others, and also there are some skills necessary for doing business offshore that we don't have”.

Axel remarks: “for us… it [offshore wind, T.L.] is too large a business”. The leading dominant CEG firms are as of yet active in the German offshore wind project tenders, but they too are running into difficulties in competing with dominant oil companies. As Leo, a senior executive at a dominant CEG firm explains:

> “So, as you know, we have to submit negative bids[146] in order to win an offshore wind auction in Germany because the market is very attractive... So, this is a highly competitive market, and you have to pay… a lot of money to the government in order to get… your seabed lease and get a grid connection. Yeah, it's basically a real estate business”.

As Axel observes: “even the large electricity companies like RWE or Vattenfall… have problems competing with… the big five oil companies... their business is ending… Perhaps not ending, but the margins are very small… I expect only a few companies will survive the competition for offshore wind parks”.

These characteristics of offshore wind generation which makes it eligible for differential accumulation stand in stark contrast to those of other RES generation in Germany as presented in the previous section. In addition, huge investments in the transmission grid are required to integrate offshore wind farms in the German Bight and bridge the spatial gap to major load centres in Western and Southern Germany (where most of the demand for electricity is located) (Weigt, et al., 2010). These high costs, and the spatial planning of grid extensions and integration, might shape future RES penetration in Germany, promoting centralization and discouraging alternative approaches and experimentation.

[146] As in the case of negative prices explained in Footnote 144, the term *negative bids* refers to participants in offshore wind tenders who bid the amount they are willing to pay in order to win the right to develop an offshore wind project.

6.2 Capitalizing residual load - how dominant CEG firms secure and shape future earnings from dispatchable generation

The previous sections supported the claim, developed on the basis of the quantitative analysis, that apart from offshore wind, for which the entrance barrier is extremely high, RES generation, or rather the control thereof, does not present a valid source of differential capitalization, for large and dominant CEG firms. Conversely, and as was suggested by the quantitative analysis, conventional energy sources, appear to be positioned within the system in such a way that they are excludable in a double sense. In the first place they can be concentrated in the hands of a small and limited set of CEG firms, and secondly, producers can readily restrict supply of CEG, and more importantly, covertly threaten to do so. In other words, in the context of the German *Energiewende*, CEG is ripe for strategic sabotage.

In this section I attempt to convey the business of CEG within the *Energiewende* and delineate the ways in which CEG firms act to shape and secure their future revenue stream.

The following, complementary, content analysis sheds light on the specific practices employed by dominant CEG firms as part of their strategic sabotage efforts which could not be traced using the quantitative data available to me. In addition, it is used to evaluate the second group of hypotheses (Hypotheses 3-6) which relate to the German case study and the relation between strategic sabotage in the context of RES penetration and the stagnation of transitionary processes described in Hypothesis 2.[147]

[147] External depth and internal breadth strategies are related to periods of increased path-dependency.

6.2.1 Strategic sabotage, system costs, and the shortage of dispatchable capacity

The following quote, taken from an interview with Clara, a senior executive of one of the German Transmission System Operators (TSOs), represents the severe shortage and critical role of dispatchable CEG capacities in the transitioning electricity system, and hence the significant leverage afforded to those who manage to concentrate them under their ownership and control.

> “This is a point: If the energy transition should work, we need that [dispatchable backup capacities, T.L.]. Everyone has to accept this. The politicians have to accept this, the regulators have to accept this because it's something needed, dispatchable power plants. Gas-powered plants are better than coal… and the intelligent thing to do is to build gas power plants that are ready for hydrogen… The German government said 10 GW will be tendered. We… together with the other TSOs, said we need 20 GW until 2031… It's not only a wish. It's really something important”.

Talking in the name of all TSOs Clara says there are two main points to convey regarding backup capacities: “We need more, and we need it quickly, until 2030, if we are to take the coal out. Because if that does not happen, the coal will have to be there somehow”.

As discussed in the quantitative analysis chapter, in the context of high-RES penetration, the threat of a shortage in dispatchable back-up capacities is imminent: insufficient reserve capacities may result in system failures, rolling-blackouts, and grid instability, thus potentially causing damage to the physical system itself, and undermining its ability to deliver electricity on demand.

Leo, a senior representative of a dominant CEG firm observes: "There's a lack of projects coming online. And so, there's sometimes a lack of competition in the support [reserve capacity, T.L.] auctions".

In addition, the coupled shortage in reserve capacity and high-RES penetration induce extremely high system costs. In order to adapt to the techno-physical and spatial generation-side changes embedded in the *Energiewende*, both the transmission and the distribution grid must be upgraded, extended, retrofitted, and transformed. These changes require immense investments, and in their absence, system operation costs increase as well, through the need to revert to expensive mechanisms such as redispatching.[148]

As has been argued in the quantitative results chapter and the sections above, the challenges to reliable electricity supply associated with the *Energiewende* are at the crux of dominant CEG firms' strategic sabotage efforts.

Nevertheless, in order for dominant CEG firms to profit from the situation, sabotage must indeed be *strategic*, that is, just enough to exclude and control, but not so much as to undermine the whole productive system: on the one hand, to keep the electricity system stable and functional; and on the other, to prevent social and political unrest due to rising electricity costs which might undermine differential capitalization in several ways such as abrupt changes in *Energiewende* policy and enforcements of revenue caps (see Section 3.10.1.2).

6.2.1.1 Strategic sabotage - not too much

The following two sub-sections trace the strategic sabotage practices engaged by dominant CEG firms. The first contemplates the hazards of over-sabotaging electricity supply, while the second presents the ways in which sabotage is wielded to increase differential profits.

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[148] *Redispatching* refers to TSOs ability to change the scheduled operation of generation plants, i.e., to instruct them to ramp generation up or down, according to system requirements. Redispatching may also refer to the rearranging of consumption schedules, i.e., demand-response mechanisms (Van der Bergh, et al., 2015).

According to Marius, a former BDEW employee, 2011 was the year in which dominant CEG firms "committed" to the *Energiewende* process, accepting its irreversibility, and striving to make it "their own". Initially, dominant CEG firms engaged in strenuous efforts to reverse the nuclear phase out. These efforts seemed to bear fruit with the conservative CDU-led[149] government's 2010 decision to extend nuclear power generation in Germany, effectively cancelling the phase out. Nevertheless, dominant CEG firms' ambition were frustrated by the 2011 reinstatement of the nuclear phase-out in reaction to the Fukushima disaster. Marius remarks that:

> "That was also the time when industry sort of heard the shot and said: Now we make a commitment… because we can't go in and out all the time, it's going to cost us a lot of money… we need planning security. So that was the time, I think, when most of the big energy players in Germany also made the commitment… it became a self-propelling process… the energy industry now was the driver [of the *Energiewende*, T.L.]".

Stephan, another BDEW employee adds: "The BDEW, I think twenty… or fifteen years ago, wasn't the biggest fan of renewables… But there has been a total complete turnaround in the past ten years", and Marius concludes: "Whether 2045 [the year set by Germany to achieve climate neutrality, T.L.] was a good idea or not, I think this needs to be left aside, but I think the overarching goal… has been now really adopted by industry, and what they now want is no further big changes".

Adrian, a senior executive of a dominant CEG firm mentioned that "the commitment of politics to the energy transition has to prevail" in order to achieve a stable business environment.

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[149] Christian Democratic Union of Germany.

Gunter, a senior executive of another large CEG firm elaborated on idea of stable regulatory conditions:

> "We have project times of at least ten years or longer and it is quite important to have these stable economic requirements so that we can deal with business cases. And any, let me say, interruptions or influences from the government, are mostly not seen as positive from an investment side. And furthermore, we need a certain incentive to invest. As I said, without any incentive, nobody will invest because the capital expenditure is so high, that means we are burning money to invest. And I think these two topics are the most important ones. We can deal with… a clear… market framework, we can deal with limited margin in the markets, and we can deal with a lot of arrangements, but most important is that they are stable".

What constitutes stability according to Gunter? On the one hand - no governmental "interruptions or influences". On the other hand, there is a clear expectation (not to say demand) to receive subsidies ("a certain incentive to invest"). Relating to global investment the company engages in Adrian says:

> "We are focusing on markets with a stable political environment… you might say… that the environment in the US is not really stable, depending on who will win [the 2025 elections, T.L.]… No, because the major decisions for power generation are taken on the state level. So, Texas is a Republican state, and they are heavily invested in renewables, so it might have an influence, but it's still relatively stable…"

Thus, *stability* relates to the ability of existing dominant business actors (in this case the power generation segment which is "heavily invested in renewables") to secure their interests. The following analysis will focus on what constitutes stability in the context of a transitioning electricity system with increasing RES penetration rates and diminishing back-up capacities as in the case of the *Energiewende*.

It seems that in 2011 dominant CEG firms in Germany shifted from attempting to control the sociotechnical terrain of electricity supply and consumption by lobbying for (and almost succeeding in) reversing the nuclear phase-out, to actively engaging in shaping the *Energiewende*, bringing it under their control, in other words “owning it”. “The role [of electricity sector firms, T.L.] has turned from more passive into more active”, says Stephan. “I would even say a few years ago, not fifteen years ago, but a few years ago, the energy companies, the TSOs, the DSOs, they understood themselves to be recipients of political ambitions”.

However, his colleague Marius describes a different state of affairs when relating to the “Big 4” dominant CEG firms: “That was a time”, he says, referring to the years leading up to and directly following the passing of the first renewable energy act in the year 2000 (EEG 2000), “when the energy world was still completely fossil. And the new concept… of phasing out nuclear, while at the same time phasing in renewables, was met with a lot of scepticism. So, the energy industry was not enthusiastic about this concept”. However, from the start the “Big 4” dominant CEG firms assumed a central role in shaping *Energiewende* policy to their own benefit: “But then the kind of deal that was negotiated to phase out nuclear power” he continues,

> “was rather welcome because it was an all-encompassing process and left industry with a lot of flexibility during the phase-out process, and if we would have stuck to the process, we would still have nuclear power in Germany, you know. It was decided otherwise at a later stage”.

Felix, another BDEW senior employee describes the unique role of dominant CEG firms in shaping this process. Referring to the *Atomkonsensus* of 2000, an agreement between the dominant nuclear power operators in Germany and the government, he explains: “The association [the BDEW, T.L.] was not really part of that process in detail… We represent two thousand companies with completely different and heterogeneous interests, and there were four big companies… for a specific interest. So, more or less, the nuclear phase out was dealt by them".

Moreover, Marius reflects that the initial nuclear phase-out deal which was negotiated "was able to garner a lot of acceptance [and, T.L.] also good will on the side of the energy industry, because [they were, T.L.] also involved from the very first minute".

So, it may be more accurate to say that the shift which occurred in 2011 on behalf of dominant CEG firms was not from passive "recipients of political ambitions" to "committed" partners, but from one course of restriction and control to another. In this case, the course of restriction and control was focused not on the complete and outright obstruction of *Energiewende* policies and related change, but on shaping this change through active participation, as suggested in Hypotheses 4-5.[150] Thus, in the new course the *Energiewende* was no longer opposed but rather, appropriated, as suggested in Hypothesis 2, which relates the active engagement External depth and internal breadth strategies to increased path-dependency.

Stephan, a BDEW employee, describes the wide reach of content and matter which business engages in to secure its interests:

> So, what the energy companies, and our association [BDEW] as well, are doing is that we are… looking also into the conditions of the energy transitions, which is not our core business. So: how much does it cost in total, how can we make the system cheaper or more efficient to reach our goals, but without causing

[150] Hypothesis 4: Adverse effects of decentralisation on conventional generation firms are compensated for through regulatory mechanisms, and the centralization of ownership over the diminishing conventional capacity which enables dominant producers to increase differential prices and profits. And Hypothesis 5: Dominant generation firms regain sectoral control by their threat to reliable supply.

> social struggles which in the end might always lead to people voting for parties revolving the whole thing, and then you don't win anything.

One could ask, why would a cheaper, more efficient system induce social struggles? but in this quote these two characteristics should be read separately, an underlying presupposition being that making the system more efficient (and perhaps eventually cheaper) requires significant public funding, whether directly from households pockets in the form of grid fees,[151] or indirectly via the state budget in the form of taxes (see Footnote 145, and following Section 6.5 in which TSO representatives describe the costs of adjusting the system to the requirements of high RES penetration). As Stephan remarks: "This is becoming a problem, particularly because we all want low energy prices, but… it means higher subsidies. So, it's a bit left pocket, right pocket. What the consumers save in energy prices, they will pay in tax…"

These struggles over the form and extent of governmental subsidy are not merely a coordinated industrial effort to construct an efficient system, but part of a wider power struggle.

CasP theory understands pecuniary earnings to be a "symbolic representation of a struggle – a conflict between dominant capital groups, acting against opposition, to shape and restructure the course of social reproduction at large", stressing that "what gets accumulated is not productivity as such, but the ability to subjugate creativity to power" (Nitzan & Bichler, 2009: 218). The content analysis of energy business representatives interviews delineate the breadth of struggle over the shaping of the *Energiewende* process embedded in its capitalization. Thus, we see a process in which dominant electricity sector firms, themselves and through their representative business association, the BDEW, increasingly act as "professional consultants" to political decision makers, assuming a major role in shaping the ways, means, and ends of the *Energiewende*.

[151] Grid fees are a component of the electricity tariff, used to finance the maintenance and expansion of the transmission network (Hanny, et al., 2022).

Stephan sums it up in his own way: “risk mitigation”, he tells me, “has become more political”. Meaning that electricity sector firms, even regulated monopolies such as the four TSOs, need to engage head-on with the *Energiewende* policy-making process in order to shape and secure expected future earnings. He claims that in the past, TSOs did not concern themselves with shaping energy policy, knowing that as regulated monopolies in a rate-of-return, or cost-plus, regulatory design,[152] they could “somehow turn over the cost to someone else, and would like to keep a margin”. Thus “if it [policy, T.L.] goes this direction - that's fine, if it goes that direction - it's fine, okay, we follow. Our own contribution is just - we make sure the grid is secure, energy supply is constant, and that's it”.

As RES penetration increased and dispatchable capacity was decommissioned, a shift occurred as TSOs became apprehensive of the limits to the ability to pass on costs in the context of soaring electricity prices. Stephan describes the TSO’s new approach as: “Okay, politicians need more contribution from our side, because the *Energiewende* is such a big paradigm change that you can't just decide on it in Parliament, you need more exchange with the different practical views”. He explains: “from a TSO point of view, it [the specifics of techno-physical changes to the electricity system, T.L.] doesn't make a difference, as long as someone pays for it. But although it's cost neutral to them, they're saying: please use option A, and not option B, because overall, otherwise we are getting political problems”.

The conditions for strategic sabotage of the *Energiewende* came together quite abruptly, as Marius describes:

> “In the beginning, I mean, that's the big temptation. We had a very robust system in Germany. And during the first years nothing had to be done… because there was enough redundancy in the system, enough reserves. And it took ten-fifteen

[152] These refer to regulatory designs in which the rate of return is predetermined by the regulator, and in which the costs of securing this rate of return are passed on to the customer along with the cost of capital (Alexander & Irwin, 1996).

years until these reserves were consumed. And all those who are warning all the time they were 'proven wrong', because they were told: Well, you see, nothing happens. but all of a sudden shit happens. And then you have to come up with a solution quickly, and we don't have these quick solutions, big fixes…. And it all came together at the time when we were struggling with the worst energy crisis in our history [referring to the onset of the war in Ukraine, T.L.]".

Felix, another BDEW employee describes how reliable supply suddenly emerged as a problem, coinciding with the period in which the results of the quantitative analysis shoe the differential rise of dominant CEG firms: "Okay, in general reliability wasn't the topic for years. It was really for specialists. So, it was not in question. And the topic came up… three or four years ago".

It can be claimed that dominant electricity sector firms are traversing the thin line of strategic sabotage - the dependence on them for system stabilization affords them the ability to shape differential earnings to their advantage, but too much sabotage (whether in the form of socially unacceptable electricity prices or system failures) may lead to the sociotechnical process spiralling out of their control.

Nevertheless, dominant CEG firms are relatively secure about the long standing ability to leverage a threat to reliable supply, which, according both BDEW and TSO representatives, will continue to be a problem seeing as the backup capacity tenders planned in the new Kraftwerkestratergie (power plant strategy), [153] are far from sufficient to meet network demands if the pace of coal decommissioning and RES penetration is to be upheld. These findings support the claim made in the presentation and discussion of the quantitative analysis results, regarding the leverage afforded dominant CEG firms by their control of backup capacities. As Stephan, a BDEW employee, says: "So, I think this [the Kraftwerkestratergie, T.L.] is one

[153] The Kraftwerkestratergie is a master plan for new power plant capacities aimed at addressing three major concerns: 1. The ability to reach the goal of climate neutrality in Germany by 2045; 2. The ability to sustain the energy intensive industries of steel and cement production in Germany under these conditions; and 3. The securing of reliable supply during "dunkleflaute" conditions (Bundesregierung, 2024).

ongoing process which we are [watching, T.L.] very carefully, but the whole sector has a similar opinion on it: Too little too late!".

Clara, a senior TSO representative expresses her concerns:

> "We came to the point now… that all the low hanging fruits of the energy transition were already picked. So, the easy part - we did it… and now comes the hard part. And the problems we are facing now - congestion in the system, amount of redispatch - it's just the tip of the iceberg".

Her colleague at another TSO, Ulf, worries over costs ("which are huge"), available materials required for grid expansion ("low capacities for very big needs, all over Europe, all over the world", "the resources the market offers to our needs to build new grids and to expand the grid, are very, very bad at the moment"), and the *Energiewende's* future, concluding: "[there is, T.L.] a very big debate in Germany… [over, T.L.] the *Energiewende* costs and whether we can afford it or not. Me personally… I'm very insecure on this question".

Most business representatives interviewed, from the BDEW, CEG firms, and TSOs alike, expressed concern regarding public acceptance, and a need to actively reshape *Energiewende* narratives in order to garner legitimacy. Felix, a senior BDEW representative, argues: "the most important thing will be acceptance. Acceptance of the *Energiewende* by the people. If you don't take the people with you… you can't do it". He goes on to explain: "we have a feeling in Germany that the middle-class fears to decline. No, that's not a good situation to do some *Energiewende* luxury, as some think it is, and they don't understand that it's also a must". He claims that the narrative must be changed as follows: "The question is do we want a system which is a little more expensive? Or do we want a system which is much more expensive? And that will be the fossil fuel system".

Albeit these stark remarks concerning public acceptance and the future of the *Energiewende*, Stephan seems less concerned: “I'm not so much worried about future elections leading to parties that are revolving energy transition, because too many people are making money out of the energy transition. And this is not going to happen. I don't think so”.

The question remains, how will the sociotechnical process be shaped and to whose benefit? The following sections trace the answer to this question, as emerges from the interviews.

It is significant to point out that, in line with the results of the quantitative analysis, rising grid fees and high energy costs are already an unfolding situation, not only a concern stemming from the imminent need to finance transmission grid expansion and upgrading. During the past two years, grid stabilisation requirements demanded an increasing deployment of redispatching mechanisms, the costs of which are rolled over to final customers. Marius, a former BDEW employee, describes the situation:

> “Until 2020, the so-called redispatch costs… were negligible. But in 2021 they were more than one billion, 2022 They were already more than two billion, last year [2023] they were more than four billion. If this continues like this, I think we're going to face a big, big problem”.

His colleague Stephan elaborates:

> “Last year [2023] the grid fees of the transmission grid exploded in a way. So, it's like six, seven, eight billion euros only because of redispatch… The whole question of redispatch is becoming an issue for them [TSOs, T.L.], because the redispatch costs are not only economic costs but political costs”[154].

A majority of these redispatch costs included reimbursements due to the curtailment of excessive RES generation in the North of Germany which could not be supplied to the Southern

[154] Here Stephan refers to the rising electricity tariff causing increasing civilian discontent, which might amount to a civil opposition to *Energiewende* policies.

demand centres due to bottlenecks in the grid,[155] and the ramping up of predominantly gas and coal fired power plants in order to meet demand (Thomassen, et al. 2024). In Germany redispatch contracts are organized outside the market through bilateral agreements between the power generation firms and TSOs (Thomassen, et al. 2024). Axel, a senior representative of a large CEG firm, remarks:

> "A dominant narrative has been that if we have renewables, we will become cheap. Yet now in reality, that is not as true anymore because the system costs are high. It is so that we expect that the operating costs of renewables are nearly zero, especially wind and solar. That leads to lower electricity prices during, say, 80% of the hours of a year. But then you have [reserve, T.L.] capacities that also have to be paid, more or less. And then we will see very high prices when the renewables are not operating and not receiving any income".

Thus, and in support of Hypothesis 6, and the quantitative analysis results and their interpretation, it seems that although skyrocketing supply reliability management expenses are presented as a techno-physical imperative raising electricity prices, it is also CEG firms' newfound leverage in negotiating differentially high prices both in bilateral redispatch agreements and in future contracts. These differentially high prices are negotiated in exchange for the reliability afforded by dispatchable capacities, and the exceptionally high power prices during low RES generation periods, which drive electricity costs upwards. In addition, as suggested in Hypothesis 2, and by the results of the quantitative analysis, differentially high CEG prices might affect the development of RES, which suffer differential *losses* (are rendered less profitable in comparison to CEG), and are shaped towards centralized rather than decentralized ownership structures. So, not too much sabotage, but also not too little.

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[155] The term *bottleneck* refers to limitations in the transmission grid's capability to transfer power according to changing conditions of energy supply and demand (Thomassen, et al. 2024).

6.2.1.2 Strategic sabotage - not too little

The following sub-sections will trace the ways in which dominant CEG firms concentrate the control of dispatchable capacity in their hands and use it to their benefit. The first section relates to the claim presented in Section 5.4, that dominant CEG firms use bilateral agreements and over the counter trading (OCT) to engage in differential pricing of dispatchable capacity.

The second section relates to the concentration and control of new and planned gas-fired and H2-ready capacities. The third deals with the control of coal-fired power plants. Taken together, these sections support and flesh-out the quantitative analysis, in which data limitations prevented me to delve into the details of these processes, allowing only for tracing them in broad strokes.

6.3 Over the Counter Trading

Quantitative data with which to confirm the claim that dominant CEG firms engage in Over-the-Counter Trading (OTC)[156] in order to secure differential pricing was lacking. While the results strongly suggested this (see Section 5.4) it is but one of the issues left undetermined by the quantitative analysis as of the completion of this dissertation. The following quotes taken from interviews held with CEG firm representatives supports the claims that dominant CEG firms engage predominantly in future and forwards marketing, both on the European Energy Exchange (EEX) futures market, and bilateral future contracts. In addition, it is confirmed that a significant part of bilateral future contracts are negotiated with large industrial firms.[157]

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[156] The term *Over the Counter Trading* refers to transactions performed directly between two parties, without the supervision of an organized trading venue.

[157] The significance of the confirmation that dominant CEG firms engage predominantly in bilateral future contracts with large industrial firms is that it supports the claim, made in the presentation and discussion of the quantitative analysis results. According to this claim decreasing conventional installed capacity and increasing VER penetration, may push buyers (retailers and industrial customers) to sign forward contracts, hedging against perceived future price rises, and enabling conventional generators to appropriate higher revenues.

All CEG firm representative interviewed confirmed that they engage predominantly in futures trading, both bilaterally and in the standardized futures markets. Axel explained: "We have the over-the-counter market where we sell electricity, sometimes also to municipal sales companies, where we make non-standardized contracts. But, also, we sell into the EEX… with future products where the conditions are clear". He stated the company mainly deals with in the case of OTC trading these contracts are unstandardized, but rather: "then negotiated with our counterparts on our own". Long term contracts profitability assessments result in: "some periods where we don't sell any electricity and then phases where we sell a lot of it in these long-term markets".

Adrian described the firm's sales strategy: "We have always tried to have sales a few years in advance. … I don't believe that we will stop this long-term selling because it gives us certainty". He explained that apart from using the standardized long-term contracts available on the exchange: "We also do over-the-counter trading, bilateral trading, with larger industrial companies". As can be learned from Adrian's previous boast, that the firm is "one of the largest suppliers of electricity for industry in Germany", these OTC contracts, negotiated with large industrial companies for which security of supply is crucial, are a major part of the firm's sales strategy.

Finally, Gunter proclaims: "our interest is to deal with a few [industrial, T.L.] contracts rather than to have, let me say, dozens of contracts. That, I think, is the general philosophy and that will not change in the future".

To conclude, CEG firm representatives confirmed that they engage predominantly in futures trading. The Bundsnetzargentur (BnetzA) and Bundeskartellamt 2023 monitoring report[158] (BnetzA, 2024: 25) teaches us that since 2019, the year in which profit per unit of generated

[158] The Bundsnetzargentur (The Federal Network Agency) is the German regulatory office responsible for networked systems and infrastructure (e.g., electricity, gas, railways, telecommunications, etc.). The Bundeskartellamt (The Federal Cartel Office) in the German regulatory office responsible for the enforcement of German competition law. They publish an annual monitoring report of the German electricity and gas networks.

conventional energy began to rise (See Section 5.1, Figure 32), "OTC clearing has accounted for the majority of futures trading". According to the report, in 2022 OTC trading accounted for 61% of total futures trading volume on the EEX (BnetzA, 2024). On the Bundsnetzargentur's SMARD platform[159] it is stated that "the electricity exchanges only make up around 20% of the total trading volume" (SMARD, 2019), implying that OTC trading accounts for a far greater share (80%), yet this extremely high figure is not reflected in the monitoring reports. Taken together, these points strengthen the claim, made in Section .54 that differential conventional price hikes are achieved via OTC trading, and leveraging large industrial actors' need to hedge against future uncertainty of supply.

6.4 Shaping differential profits through bilateral redispatch contracts - a quantitative interlude

At this point it was clear that I should go back to the numbers and try to understand whether bilateral redispatch contracts played a part in dominant CEG firms' shaping of their stream of present and future earnings. What I found was that not only had aggregate redispatch costs soared as reliable supply management became more and more complicated and the occurrence of grid bottlenecks increased (as I was told by TSO, BDEW, and CEG firms' representatives alike), but the prices per kWh which generation firms managed to negotiate in bilateral contracts were persistently rising, and at a pace disproportional to the rise in the amount of redispatched power.

[159] An online platform displaying electricity market data collected by the Bundsnetzargentur.

Table 21presents the estimated aggregate cost of redispatched power, its amount in GWh, and an estimation of price per kWh.

Table 21: Redispatching and countertrading in Germany, 2015-2022

Year	***Total volume (GWh)***	***Estimated aggregate cost (€m)***	***Average price (€ / kWh)***	***Change in total volume (%)***	***Change in cost per kWh (%)***
2015	15,436	436	0.03		
2016	11,475	235	0.02	-26	-27
2017	18,456	421	0.02	61	11
2018	14,875	388	0.03	-19	14
2019	13,323	291	0.02	-10	-16
2020	16,561	375	0.02	24	4
2021	20,405	987	0.05	23	114
2022	29,534	3,208	0.11	45	125

Source: BnetzA, 2023: 109, Electricity: congestion management measures; BnetzA, 2019: 141, Electricity: network and system security measures; BnetzA, 2018: 121, Network and system security measures.

As can be seen in Table 21, the average price of redispatching and countertrading power between the years 2015 - 2022 lay between 0.02 - 0.03 € / kWh and was relatively stable, despite fluctuations in the total volume of redispatching and countertrading power which ranged between -26% - 24% annual change. In 2021, however, a 23% increase in total volume corresponded with a more than doubling of the price per kWh compared to the average price between 2015 - 2020 (114% change), while the following year an increase of 45% in the total volume corresponded with a price per kWh which was 2.2 times higher than the price in 2021. Unfortunately, at the time of the writing of these lines, the data for 2023 has yet to be published, but Stephan, of the BDEW, and other interviewees informed me that the cost of redispatching more than doubled, perhaps tripled ("Last year [2023, T.L.] the grid fees of the transmission grid exploded in a way. So, it's like six, seven, eight billion euros only because of redispatch").

Here, two points are important to stress: 1. While these costs are rolled on to the customer via the grid fee component of the electricity tariff, they are in fact load-management expenses which correspond to generation segment earnings; and, 2. While the total physical volume of redispatching and countertrading increased, the rise in the price which generators received per kWh by far outstripped the physical rate of growth, hence rising aggregate redispatching costs resulted as much from the higher revenues of generation firms, as from increased congestion management requirements, if not more.

Though it could be claimed that these revenues were not translated into earnings in 2022 because of high natural gas prices, a closer look at the energy source breakdown of conventional power plants deployed in redispatching in 2021 and 2022, presented in Table 22, shows that coal-fired power plants have the highest deployment rate. Nevertheless, this is physical data, and we do not know the differential pricing of gas-fired and coal-fired generation and how the revenue is distributed.

Table 22: Conventional power plant deployment for redispatching by energy source, Germany, 2021-2022

Year	***Lignite***		***Hard coal***		***Natural gas***		***Nuclear***	
	reduction	***increase***	***reduction***	***increase***	***reduction***	***Increase***	***reduction***	***increase***
2021	1,653	40	2,412	3,398	180	847	953	5
2022	3,131	156	2,240	5,741	204	2,055	221	8

Source: BnetzA, 2023: 111, Electricity: Power plant deployment for redispatching by energy source in 2022; BnetzA, 2022: 172, Electricity: power plant deployment in Germany in redispatching by energy source in 2021 (GWh)

Though the data is, as yet, incomplete (i.e., lacking differential pricing by primary energy source), Redispatching prices, set in bilateral contracts, are a peephole to the ways in which dominant CEG firms shape the level and extent of their revenue stream, using OTC trading. OTC contract details are unexposed to the public, as are the specifics of redispatch contracts. Nevertheless, the analysis presented in this sub-section can shed light on the mechanisms through which dominant CEG firms negotiate differentially high prices, in the context of decreased reliability of supply.

6.5 Gas and H2-ready plants

Apart from engaging in differential pricing through bilateral and future contracts, dominant CEG firms can act to exclude others from participating in the new gas-fired and H2-ready reserve capacity, thus effectively concentrating the control of reliable supply conditions in their hands and working towards differentially shaping the stream of future earnings from this control.

6.5.1 Concentration of new thermal projects

In Section 3.7.2.1, the concentrated condition of nuclear power ownership in Germany was presented (As Felix remarked, "[in the, T.L.] nuclear phase out there were four companies" the historically "Big 4" electric utilities). It seems that CEG firms expect to achieve the same degree of concentration with regards to dispatchable reserve capacities. The following analysis is a supplement to the quantitative analysis, in which centralization of CEG capacity was detected (see Section 5.3), but the mechanisms behind this process were left unexplored.

Clara, a senior TSO representative, foresees the concentration of reserve capacities under dominant CEG companies which are in a unique position to make the large investments required, handle project complexities, and secure the land on which to construct. Speaking of the future role of dominant CEG firms in the electricity system she says: "their role is important because… either they will be operating these plants we still need [existing dispatchable capacities, T.L.], or they will probably be the ones that will invest in new ones that are dispatchable".

Axel, a senior representative of a large CEG firm, also expresses his confidence in the inevitability of reserve capacity concentration in Germany. Referring to the two dominant CEG firms he says: "They probably will win a lot of these tenders [tenders for the 10 GW of H2-ready power plants planned under the Power Plant Strategy (see Footnote 153, T.L.]... I would expect that these backup capacities will, in the end, be operated by five or four companies in Germany, not more".

Stephan, of the BDEW, explains why under the current conditions of uncertainty in regulation, and with the high level of investment required, only dominant firms can afford to participate in the upcoming tenders for H2-ready: "A big company, like RWE… can say: we're building it anyhow, this H2-ready power plant… there will be some kind of regulation, and whether it's A, B or C, it's fine for us. if you're small you can't do that".

The decision to tender four blocks of 2.5 GW (Bundesregierung, 2024), rather than divide the 10 GW to smaller blocks, reinforces the advantage of dominant CEG firms.

Leo, a dominant CEG firm senior executive, confirms this view: "as a company we are very well able to cope with complexity, and it's not everybody's business, but I think we could cope with that very well".

Accordingly, while some companies struggle with location problems, and are not able to commit to build new H2-ready power plants while still obliged to keep existing coal-fired capacity online, large CEG firms report no such concerns. Leo continues to remark: "We do not have so many problems because our sites are sufficiently spacious. So, I think we can do both", explaining that:" if we find ourselves in a favourable investment environment within one or two years, we will be able to use these [existing, T.L.] sites to build out significant new capacity". Yet he later further qualifies this statement:

> "Yeah, but that depends on what the power plant strategy and the capacity market exactly will look like. we do not endeavour in economic decisions for the sake

> of security of supply. That we do not do. And… I'm not aware of anybody else who's going to do that".

According to a recent study on the cost differences between H2-ready and conventional gas turbines, the expected cost increase of H2-ready gas turbines in relation to conventional gas turbines amounts to 8.5% (Freitag et al., 2024). This cost gap does not explain the confidence with which the interviewed dominant CEG firms, and TSO representatives, assume the ownership concentration of reserve capacities under dominant CEG firms.

It seems that the major advantage of dominant CEG firms which enables their control of new dispatchable capacity stems from their institutional characteristics, their location within the sociotechnical system, and their ability to act within the changing regulatory framework and capitalize uncertainty. Thus, it is an expression of organized power.

The following two sections will trace the ways in which dominant CEG firms endeavour to shape and secure future earnings from reserve capacities. This analysis adds on to the quantitative analysis in that it traces the specific advantages of dominant CEG firms in the context of the *Energiewende* and dispatchable capacity concentration which were only assumed in the quantitative section.

6.5.2 Securing subsidies with the threat of blackouts

Due to their dominant position and the systemic dependence on them as the sole (private) actors big enough to build and operate the crucial reserve capacity, dominant CEG firms were able to secure high subsidies for the construction of new dispatchable capacity. It has been published that the German government has conceded to allocate 16 billion Euros in capital and operation subsidies to the winners of the planned 10 GW H2-ready capacity tenders (Alkousaa, 2024).

Stephan, a BDEW employee, points out: “without subsidies, I don't know who's investing in energy, in particular… energy generation. There's a problem. And this is also a… general political problem, because essentially, we're subsidizing everyone, and still, everyone is complaining”.

He continues to describe a basic paradox of privatization which arises as Germany attempts to fundamentally transform its electricity system: “we all are happy about low energy prices, but low energy prices mean you need to give more subsidies. Otherwise, no one will be investing in generation”.

Large and dominant CEG firms have made it clear that without significant public subsidizing, these essential capacities will not be constructed. Axel, a senior executive of a large CEG firm, explains: “If you have money, you normally invest in renewable production. Or we try to invest in such tenders for backup capacities, or… hydrogen production... But this is a very new business, risky, and often you are asking for subsidies”. While Gunter, the project manager of H2-ready plant development of another large CEG firm, adds:

> “We are developing at three sites… projects, let me say, to close the capacity gap at certain hours. But we need… the political framework, and also the economic framework, [so, T.L.] that we can realize these projects, because without these… subsidies or support to build new… non-renewable capacity into the market, it's not economical”.

He continues to explain that subsidies are needed to secure desired profit margins. He explains that electricity prices have been very volatile over the past years, and future projections vary significantly, depending on the pace of RES penetration and natural gas price variance. Thus, to shape and secure desired, differential, returns, public subsidy is required:

> “The general level of electricity prices is not high enough [so, T.L.] that we can bring new… gas-fired power plants onto the market. We will not get the returns

> to have a profitable project. That's why we are asking the government for a subsidy. I mean, it could be over the operations, it could be… a CapEx fee [Capital Expenditure, T.L.], and that brings us to the position to invest. Because our shareholder says: 'Okay, we would like to have a certain margin on the project. Without the margin, we will not invest in the project'. That means the government or state is obliged to give investment security".

Thus, large public subsidies, which are necessarily directed into the hands of dominant CEG firms, and which non-dominant firms are excluded from, are aimed at shaping and securing a differential profit margin.

6.5.3 Capacity markets

The institution of a capacity market mechanism has been strongly advocated for by electricity sector businesses in Germany, who regard it as necessary to secure desired profit levels.
Gunter explains that the company is "doing lobbying work and showing that it [a capacity market, T.L.] is necessary because all of us, we are private companies, and we are not state-owned utilities. That means we need to have a business case or margin on the project".
As Felix, a senior BDEW employee explains, this mechanism had been lobbied for by the association for over a decade: "Our association made a proposal for [a, T.L.] capacity market in 2014, because it was already obvious that we must change the system from a market based on kWh, to based also on reliable capacity". This proposal was rejected by the German government, who instead opted for an "energy only" market design: "in my opinion, the idea [instituting a capacity market, T.L.] was good, but it was too early, it wasn't acceptable…. politics didn't want that. They were still thinking of over-capacities and so didn't see any problem". Yet today, a decade later, the "topic is on the agenda again, now driven by

politicians, or by the ministry… and they announced that they want to implement a capacity mechanism [by, T.L.] 2028".

Moreover, it seems this announcement has now halted reserve capacity construction, since, anticipating higher profits, CEG firms will not invest before the capacity market is in operation. As Leo, a dominant CEG firm representative, explains: "The problem is, once you have started announcing a capacity mechanism, this is becoming itself a self-fulfilling prophecy. So, nobody will invest. This is exactly what we've seen right now. And so, we need a capacity market". Leo describes a situation in which, although investment in gas-fired power plants may be profitable under existing conditions, all such investments have now come to a standstill, seeing as they are no longer *differentially* profitable. Referring to dispatchable investment decisions taken two years earlier he says:

> "We could adopt that decision [to build new gas-fired power plants, T.L.], because we think that these investments were economic. So, they became investable also, due of course to some CHP[160] subsidies… we are convinced that these investments will pay off... But afterwards, the public announcement was made that the capacity market, and the Kraftwerksstrategie [power plant strategy, T.L.], would be implemented. So, we haven't seen any significant investments in thermal conventional power generation since".

Once more, the differential profits expected are relevant only to dominant CEG firms, who are expected to build and operate the H2-ready receive capacity plants, due to their institutional advantage. Moreover, as Gunter points out, the capacity market is designed to cater specifically

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[160] The acronym CHP stands for Combined Heat and Power and refers to technologies which generate both electricity and thermal energy at high efficiencies. Seeing as district heating is a crucial and energy intensive industry in Germany, predominantly powered by fossil-fuels, the Act on the Retention, Modernization and Extension of Combined Heat and Power Generation (KWKG) aims to incentivise and support CHP plant construction.

for certain technologies, peaker H2-ready gas turbines,[161] which dominant CEG firms intend to control: “we have one group of projects which are still looking at market revenues… mid-loading capacity[162] for example. If you talk about capacity markets, it's really peak-designed”.

6.6 Coal-fired power plants

Another component of conventional power generation in Germany are coal-fired power plants. Over these looms the prospect of the coal exit, which Germany would like to achieve by 2038 (with RWE negotiating their own coal exit by 2030). Yet the feasibility of this planned schedule is questioned in light of current and expected load-management requirements. In either case, as of the timing of the interviews (2023-2024), the year 2038 is still far enough for large CEG firms to use their coal-fired power plants to shape differential profits based on the systemic dependence on decreasing dispatchable capacity.

The dominant CEG firm RWE declares its intention to decommission its coal-fired power plants by 2030, focusing on concentrating gas-fired and H2-ready reserve capacities, and large-scale wind projects in Germany as well as globally, under her hands. This also makes sense with regards to the “peak-designed” capacity market and redispatching contracts.

Table 22 shows that gas-fired power plants are used for redispatching increases, rather than lignite-fired power plants. Nevertheless, as the following analysis suggests, other large CEG firms do not appear to be in a hurry to decommission their coal-fired power plants. Some even engage in concentrating existing coal-sourced capacities under their hands. Thus, Axel, a representative of a large CEG firm which has recently been purchased by a larger CEG company explains:

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[161] *Peaker power plants* are power plants which are dispatched only during peak load, when power demand is high and exceeds base-load capacities (Chojkiewicz & Phadke, 2024).

[162] In the term mid-loading, the speaker is referring to load-following plants, which are situated between base load and peaker plants in that, unlike peakers, they are continuously dispatched, yet not at nameplate capacity, and “follow demand” by adjusting their output accordingly (Locatelli, et al., 2015).

> The strategy of [our current owner, T.L.] is to buy companies in trouble that are cheap and then try to make the most of them. And [our former owner, T.L.] had not received much money for our operations because [our former owner, T.L.] had a negative forecast… for the lignite operations. And so, they sold it very cheap to [our current owner, T.L.]. [Our current owner, T.L.] assumed that the nuclear phase out will lead to higher electricity prices. But then… the war in Ukraine started. And the gas prices became crazy. And so, we earned in the last years [many, T.L.] billions of Euros. And let's say the bet of [our current owner, T.L.] has been fulfilled by Putin".

It is important to point out here, that even without the war in Ukraine, the new owner calculated that buying up coal-fired generation capacities in Germany would be profitable, for the time being, due to the sociotechnical effects of the *Energiewende*. This new owner did not only purchase the large German CEG firm, it also continued to purchase coal-fired power plants from smaller firms in Germany, thus concentrating the remaining coal-fired generation capacity, as Felix, a senior BDEW employee, describes: "On a smaller scale if you are a local producer and just own one coal power plant then I think it's [buying existing coal-fired power plants in Germany, T.L.] not useful". However, he continues to say that "there were some structural changes" in coal-fired generation and describes the purchase of coal-fired power plants by the new owner of the large German CEG firm. He later remarks, regarding coal-fired power plants in Germany: "there was no one just buying them all, except maybe [the large firm mentioned earlier, T.L.]".

Marius, a former BDEW employee, explains that coal-fired power plants are still needed, not only as system service providers (for load management) but also for district system heating, which is still heavily coal reliant in Germany:

> "So now, we keep many of these power plants in play because they're not just working as electricity providers… They also serve as system service providers… but especially, many of them, in the wintertime, also provide heat. Municipal central heating systems, for instance. So, the efficiency is high. So even if they can't make money with the production of electricity, they can generate enough income through the sale of the residual heat. That's important, in Germany, to keep in mind".

Felix raises the same concern regarding the dependence of central district heating systems in Germany on coal-sourced generation. Here he differentiates between small and medium scale operators, and larger ones, who operate large plants and have many customers:

> "In the end it's still a question of reliability… if we talk about the phase-out of coal, we also talk about heat and CHP. Most of them are CHP power plans. So, the question is how to replace the heat, for district heating if you shut down coal power plants. So, this is a difficult topic at the moment for some, because they are big, a lot of customers, and it's not easy to replace them with decentralized solutions for district heating".

All in all, there is a strong awareness of the new and critical role of, and the dependence on dispatchable power plants in the transitioning electricity system, a dependence which is assumed to last for two-three decades in the least. This may not seem too long in terms of sociotechnical transformations, but it is definitely enough time to plan and secure the differential capitalization of this dependence. Felix expresses the basic conception upon which dominant CEG firms act:

> "We argue: Transformation means that you have a certain period of let's say, one, two, or three decades, where you run parallel infrastructures, a fossil infrastructure [system, T.L.] and a renewable infrastructure [system, T.L.]. So,

> running two systems will increase costs for some years. In the end, let's say, 2045 or 2050, I'm pretty convinced that a renewable system is the cheapest system, compared to a fossil fuel or any other system. But for the next twenty years we run parallel structures".

And this expensive, double system, can be a source of differential profit, if the ownership of the fossil-fuel part can be concentrated, and its control used to extract higher earnings.

This is true not only to natural gas, but also to coal. When asked about the coal exit, Felix remarks: "Reliability of the system is really the question now… if we do not build up backup capacity fast enough now, we will need some coal power plants in the thirties".

6.6.1 Coal profits and subsidized decommissioning

This section explores the ways in which large and dominant CEG firms have managed to secure differential income from operating coal plants in the context of the coal exit, whether through decommissioning or prolonged operation periods.

Gunter expresses optimism regarding the firm's ability to profit from the current socio-technical conditions of the German electricity sector:

> "I'm generally optimistic. But… we need to have a certain speed on the increase of renewable capacity... Furthermore, the step out of coal is practically not as fast as we expected. We definitely see right now the first signs from… the government, they're working on the capacity market, which helps to secure… energy supply. And I'm also quite optimistic that we have projects which can serve this market... From a company point of view, I'm optimistic. From a country point of view, I think we are behind our plans".

Stephan, of the BDEW, describes the perceived risks of owning coal-fired generation capacity, in light of the uncertain coal exit conditions:

> "For… conventional generators… planning insecurity is the biggest problem. You don't know whether by 2030 you can close down your coal Power plant or not. Because officially on the paper you can, but at least without an effective coverage strategy [for reserve capacity, T.L.], we don't have enough capacity, so you need to keep them somehow. Which means, what do you do with the personnel? Do you tell them you can go somewhere else by 2030, or do you need to keep them?"

He points out that, though at the time of the interview, running coal-fired power plants was profitable, because the EU ETS (EU Emissions Trading System) certificate prices were low, he does not expect such low prices in the future. Thus, keeping coal-sourced generation capacity would be unprofitable, unless "you have the future expectation that there [will be, T.L.] enough hours with high prices".

Large CEG firms which operate large coal-sourced generation capacities do not seem too concerned. While planning uncertainty may be a problem for smaller firms, as we earlier saw, these firms are large enough to deal with some regulatory uncertainty. Scepticism regarding the feasibility of the planned coal-exit schedule allows them to hold on to these power plants while they are still profitable and rely on a subsidized decommissioning process when market conditions change. Axel, a senior representative of a large CEG firm which is heavily invested in coal, says: "in the end, lignite can operate until 2038... But we only have 12 GW [of H2-ready reserve capacity, T.L.] that are tendered. And for that reason, we foresee a scarcity if it comes to a full coal phase out in 2030, and everybody in the market fears that".

While regulators assume that a "market-driven coal phase-out" will occur by 2030, he points out that in this case "you need replacements. And only… 13 GW is [not enough, T.L.]. There's a calculation by… BnetzA [the German Federal Network Agency, see Footnote 158, T.L.] that they need at least 21 GW by 2030", this calculation itself assumes the fulfilment of further techno-physical changes to the grid, for example: “that demand response will work, that a lot of storage will come in”. Regarding their own coal-fired generation he explains:

> “The German government, or a lot of their advisors, expect that it [market-led coal phase out, T.L.] will happen before 2030. We say: ‘Perhaps’, but we don't use such long-term prognosis. We look at the market. If the market signals us that we have to stop our operation because we make losses, then we will decide on that, but not based on market price studies for 2030, 2040. That is not sufficient. We operate as long as it seems to be profitable”.

Hence, the focus of large coal-sourced generation operators is on running their plants at a profit while conditions allow this and then receiving the subsidy for decommissioning when conditions change. Gunter adds: “Our new shareholders… said: ‘Okay, yes, [we, T.L.] would like to have… a black [coal-fired, T.L.] part [in our portfolio, T.L.], but with a clear exit strategy.’... it's not feasible for them to still have coal-fired power plant operation in ten years”, nevertheless “they definitely see the role of… energy security”. This expectation for high power prices due to periods of low RES generation and related load-management requirements means that large CEG firms are in no rush to decommission their newer coal-fired power plants. Axel explains:

> “Our… investor looks more or less daily into the next three years, and if the market prices are okay, we operate. A real certainty you don't have… but if we don’t have enough backup capacities, that could lead to high electricity prices during a few hours… it could be sufficient to operate our plants longer [than 2030, T.L.]”.

These clarifications shed light on the ways in which CEG firms lower their differential risk. This in comparison to alternative electricity generation, a field in which the reversal of the governmental subsidy policies and uncertainty regarding the fulfilment of required transmission grid and storage development has raised risk perceptions.

Moreover, while the newer, modernized coal-sourced power plants are kept on the market, large CEG firms use decommissioning tenders to receive subsidies for taking older, less profitable installations, off-line at a profit. Axel, representing a CEG firm operating large coal-sourced capacities, describes: “The EU ETS…prices were too low [in relation to, T.L.] the electricity prices to close our lignite plants earlier”. He explains that low CO2 certificate prices and high electricity prices did not justify the decommissioning of coal-fired power plants. Nevertheless, “our oldest plants are 500 MW blocks. [We closed, T.L.] three of them… in 2017... We received money for that, perhaps somewhat higher than it normally costs. That was, let’s say, a political compensation”. He continues to add that these decommissioned plants were later brought online again, due to the rise in natural gas prices induced by the war in Ukraine, thus enjoying both decommissioning subsidies and “prolonged production time” at differentially high prices.

6.7 Qualitative analysis conclusion

To conclude, while uncertainty regarding the coal-exit is presented as increasing the risk perceptions of CEG firms, it seems that they have succeeded in leveraging their dominant and pivotal position in order to secure their profits in any case – whether decommissioning will proceed as planned or coal will continue to be burned.

The qualitative analysis presented in this chapter draws on the results of the quantitative analysis and seeks to explore undetermined questions.

The analysis presented above supports the second group of hypotheses (Hypotheses 3-6), and trace in greater detail the business strategies deployed by dominant CEG firms in order to boost their differential accumulation and income.

In line with the theoretical framework's assumptions, it seems that the transition to RES, which harbour lower depth and breadth energy capture potentials,[163] is accompanied by a set of strategic business sabotage measures which impede on transitional processes, inducing stagnation and possible reversals.

In the case of the German *Energiewende* CEG firms must traverse the thin line of strategic sabotage to regain their dominant position. The strategic sabotage emerging from the quantitative analysis includes the following features:

1. Dominant CEG firms actively engage in the shaping of *Energiewende* policy and decision-making, making the process "their own". While they do invest in RES, within Germany this is not their main source of differential accumulation (with the exception of offshore wind projects).
2. The strategic sabotage of the German electricity system and its transitional processes balances the ability of dominant CEG firms to leverage their pivotal position as holders and controllers of dispatchable back-up capacities in differentially raising prices with the need to sustain a functioning and reliable electricity system, devoid of rolling blackouts, and keeping the electricity tariff low enough as not to spur excessive public discontent and civil unrest.
3. Dominant CEG firms use their position to differentially raise the conventional tariff on OTC contracts, as in the example of redispatching contracts.
4. In addition, they strive to centralize new and existing dispatchable capacities under their hands.

[163] To illustrate, the energy densities (measured the quotient of exergy contained in a system and the volume of the system) of solar RES are significantly lower than those of non-renewable energy sources (van Zalk & Behrens, 2018). In addition.

5. All the while, they differentially reduce the risks associated with the uncertainty of the coal-phase-out so as to position themselves to gain from any outcome of the process.
6. Finally, these developments influence not only dominant CEG firms' differential accumulation, but also the *Energiewende* transitional pathway. RES development is becoming increasingly socially and spatially centralized as it is being subjugated to "the market," where the power of dominant capital has reasserted conventional generation as a superior business choice. At the same time, as dominant CEG firms' interests become enmeshed with the perpetuation of the reliance on dispatchable capacities, so do the possible solutions to the challenges of high-RES penetration get narrowed down to privatization and a reliance on natural gas.

7. Discussion

7.1 Ordering transition - a discussion of the *Energiewende* case study

In the following discussion of the *Energiewende* analysis results, I reflect on the dialectical relations between techno-physical change and organized power, industry and business, and the ways in which they constantly shape the energy transition. These dialectics are evident in the effects of the rapid and significant decarbonization of the electricity system in Germany on dominant firms in the sector, and in the ways in which the actions, reactions, and inaction of organized power in the sector affect transitional pathways.

In other words, I will discuss the ways in which the channelling and domineering translation[164] of industry through business shapes decarbonization processes under capitalism (for a discussion of domineering translation see Section 2.1.2.1).

In RWE's (2016: 5) annual report for 2016, then CEO, Rolf Martin Schmitz, is quoted as saying:

> "RWE already ensures a reliable supply of electricity. However, this function will become increasingly important. In the future, our focus will be on making generation capacity available when it is needed rather than just producing kilowatt hours… Our new motto is 'Powering. Reliable. Future.' I am optimistic that sooner or later we will receive adequate compensation for the security of supply that we provide."

It appears that the "adequate compensation," of which Schmitz was so optimistic, arrived sooner rather than later. Although the restriction of conventional production was dictated to

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[164] In Chapter Two, I defined domineering translation as the dialectic dynamics between two *conflicting* social logics, in which the expression of one logic is forced through the other.

business and at first resisted, following an initial destabilization, dominant electricity firms in Germany derived a mechanism through which to exploit the regulatory framework to their advantage, and regain sectoral control, for the time being. As I have shown in the quantitative analysis, The mechanism leverages the increased risk to reliable electricity supply due to VER penetration and conventional capacity decommissioning. Schmitz himself put it simply: the point is making available (read: controlling) "generation capacity when it is needed rather than just producing kilowatt hours" (RWE, 2016: 5).

Similar processes, such as the re-emergence of coal in the context of high VER generation, and the incentive to secure electricity supply using forward contracts ("contract cover"), have been identified in the UK (Atherton, et al., 2023) and in Australia (Rai & Nunn, 2020), respectively. I describe this as strategic sabotage, since income is extracted not from production itself, but from its control, backed by the implicit threat of withholding conventional generation. In addition, I argue that subjugating the operation of a critical techno-physical nexus in a transitioning system to the logic of differential accumulation (read power), bears consequences for the transitional process itself.

Indeed, as these sabotage dynamics unfold, RES development displays increasing spatio-physical and ownership concentration trends, alongside decreasing penetration rates (for the analysis and results on which these observations are based, see Appendix 11).

The double centralization of RES[165] is accompanied by a declining alternative electricity tariff and a general policy push toward market-based mechanisms. This move away from direct public subsidy makes RES development increasingly dependent on, and susceptible to, "market forces". RES projects' return on investment depends more and more on market prices, and those are increasingly shaped in favour of conventional generation control. For example, the

[165] I refer here to a process of *double* centralization as RES are becoming more centralized both spatially and regarding ownership structure.

move from the FinT[166] to a market premium mechanism means that EEG eligible generation is compensated for the difference between a regulated ‘value to be applied’ and an averaged market spot price. If RES’ sales prices trail behind the average price, they suffer an income loss. Moreover, the market-exposed regulatory framework can be expected to promote centralization, as small actors, cooperatives, and citizen energy projects might be disadvantaged compared to big ownership formations controlling RES (Morris, 2019; WWEA, 2019). The latter can strong-arm their way through market complexity and business risk.[167] Thus, the *Energiewende* project becomes intertwined with dominant capital, as it reshapes the electricity sector.

The shaping of transitional pathways can also be seen in the control of conventional installed capacity development. The qualitative analysis indicated that once dominant German CEG firms ceased resisting phase-out and RES development mechanisms, and began an effort to shape them, they have become invested in the strategic sabotage of the *Energiewende* (for a discussion of strategic sabotage, see Section 2.2.4). Instead of an outright opposition to grid decarbonization, dominant CEG firms are banking on a constrained perpetuation of VER penetration, which is itself shaped in their interests - increasingly centralized, offshore-wind-based, and “market oriented”. It is in this context that their control of flexible back-up capacities, and of new large-scale RES capacities, earns them their renewed dominant position and the lever of differential accumulation.

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[166] The fixed Feed in Tariff (FinT) for RES is a fixed, above-market price for renewable energy sourced electricity generation

[167] The advantages of large-scale businesses in this context may include greater access to resources, subsidies, and economies of scale, greater capacity for adaptation and diversification, higher purchasing and market power, and simply a greater capacity to deal with complex bureaucratic processes. among others. Nevertheless, even dominant utilities might find themselves ousted from high-profitability areas such as offshore wind by bigger actors, e.g., multinational oil companies. This has recently occurred in the auctions for offshore wind capacity in the North Sea. 0-cent bids effectively turn the auctions to real-estate auctions, where the highest bid for the area wins. Thus, BP and TotalEnergies could easily outbid all other participants (Amelang, 2023). It has also been noted by the CEG firms’ representatives which I interviewed (see Section 6.1.1).

And so, the sabotage of the techno-physical characteristics of electricity supply and decarbonization processes must be doubly strategic: not so much as to "unsustainably" raise prices and cause public unrest and resistance to grid decarbonization policy, and also not so much as to undermine the reliability and sustained operation of the electricity grid; just enough to constrain and control VER penetration, without overturning the process, and exert differential profit from the control of back-up capacities.

Arguably, business-regulation relations, or the state's capitalized logic, have been pivotal to dominant firms' current recovery. While dominant electric utility firms were at first unsuccessful in their attempt to block and overturn *Energiewende* processes, they have secured a central position in determining their conditions. Having made the project "their own," they engage in reshaping it to their advantage, in a manner that affects the sociotechnical features of decarbonization, i.e., the centralization rate, ownership structure, and democratization of electricity generation.

Moreover, the neoclassical logic which dictates the increasing liberalization of RES penetration is embedded in national and supranational regulatory frameworks like those of Germany and the European Union. Consequently, although the FinT mechanism was a longstanding and central component of the *Energiewende*, the move to the auction system was "the result of a path-dependent process of incremental changes towards greater market-orientation" (Leiren & Reimer, 2021: 96).

Why do dominant firms continue to rely on allegedly "obsolete" energy resources and technologies? The answer partially lies in the techno-physical features of the majority of RES, namely variability and uncertainty. The study's findings demonstrate the significance of generation *control*,[168] rather than output quantity, to differential profits. Variable electricity generation is, by definition, harder to control, so it requires tighter industrial coordination and

[168] Generation control involves the ability to manage the timing, quantity, and quality of generation output.

regulation. Indicative of this is the EEG legislation that mandates the sale of RES electricity, making 'withholding' irrelevant. Given this business disadvantage of RES, and even with the prospect of a complete coal exit by 2038, dominant firms may find it profitable to continue "betting on coal" and concentrating gas-fired capacity in their hands. They have, at any rate, managed to reduce the risk associated with the uncertainty of the coal-phase out by operating coal-fired power plants so long as prices are differentially profitable, and enjoying phase-out subsidies once this will cease to be the case.

Ultimately, it is the public who pays the price for dominant capital's differential gain. This is true in the sense that sabotage-induced price hikes are rolled on to consumers, as well as in terms of the broader implications of the capitalization of *Energiewende* policies. Arguably, the regaining of control over the electricity segment by dominant firms, coupled with the regulatory shift toward market mechanisms, is already becoming evident in the *Energiewende's* sociotechnical trajectory: RES development, which initially displayed strong civic participation, is becoming increasingly socially and spatially centralized as it is being subjugated to "the market," where the power of dominant capital has reasserted conventional generation as a superior business choice.

A major insight this study offers is that electricity exchange prices alone are often useless in the study of dominant capital. As a major share of electricity trading is done via over-the-counter contracts,[169] exchange prices cannot be used alone to study differential patterns. To this end, I used aggregate accounting records, which revealed a hidden process of price formation. In my opinion, the missing public information on the sector, which conditioned the current research trajectory, is part and parcel of the power relations being researched. In-depth interviews with electricity sector business representatives pointed towards redispatching prices,

[169] According to BnetzA's SMARD platform, "trading on the electricity exchanges only makes up around 20% of the total trading volume", leaving around 80% for OTC trading. And yet, "the electricity prices on the exchange are regarded as an indicator for the general wholesale prices" (BnetzA, 2023).

set in bilateral contracts, as one of the mechanisms through which dominant CEG firms differentially shape the level and extent of their revenue stream. This is part of the capitalization of the systemic dependence on dispatchable backup capacities which rest upon both investment in newly planned and commissioned gas and H2-ready facilities, and the operation of existing coal-fired power plants.

Returning to Hypotheses 1 and 2, and the analytical perspective from which they are derived, it could be stated that a decarbonizing transition has transformative potentials. Regarding energy capture, a complete decarbonization of the national electricity grid, using existing and feasible technologies (and under the conditions of a complete nuclear phase out) would entail a coupled *decline* in the breadth and depth of energy capture. The amount and diversity of primary energy conversion would be reduced, all the while that conversion efficiency would diminish. In contrast to the changes in breadth and depth of energy capture which characterised the transition to fossil fuels, enabling the energy-core to *differentially* accumulate using internal depth (cost-cutting) and external breadth (greenfield investment) pathways, these are not available as differential accumulation pathways in the context of contemporary electricity sector decarbonization.

Dominant CEG firms in Germany know full well that they will not secure and hold on to their dominance through greenfield investment in RES capacity, or cost-cutting efforts. I argue that for external breadth and internal depth to act as *differential* accumulation pathways certain sociotechnical conditions must be fulfilled: external breadth pathways must offer the opportunity for significant *centralization* of new industrial capacities; internal depth pathways must offer the potential for exclusively, or at least disproportionately, controlling or benefiting from increasing technological efficiency or decreasing input costs.

As these conditions do not apply to RES capacity development in the *Energiewende* context, dominant CEG firms' business strategy relies on the restriction and constraint of transitional pathways, leading to socio-technical stagnation. Thus, dominant CEG firms must traverse the thin line of strategic sabotage - not too much so as to undermine the sociotechnical system of electricity generation and restricted transition, and not too little so as to lose the leverage which affords them differential profits.

The concept of social power has been used to study the German *Energiewende* process as it unfolds. Institutional and policy studies have focused on the power of key stakeholders and interest coalitions to influence transition processes,[170] while other research emphasized broad social conflicts, and struggles over energy justice issues (Becker and Naumann, 2017; Ernst & Fuchs, 2022; Leiren & Reimer, 2018). Analysing contemporary transitional processes through the lens (and conceptual tools) of capitalist power and its interaction with industrial change and potentials informs us of the ways in which the *Energiewende* is reshaped as parts of the strategic sabotage of the transitional socio-technical process at large. In this sense, the power processes uncovered in the *Energiewende* case study analysis exceed those embodied in the idea of market power.[171] They regard the capacity of dominant CEG firms to strategically sabotage the transitional process itself.

To regain sectoral control and differential accumulation dominant German CEG firms needed to contrive a mechanism through which to regain control of the industrial process, its scope, pace, and direction of change. As discussed in Section 2.1.2.1, this control is never complete or permanent. However, it does, as I write these words, take part in creating transitional legacies and trajectories which become increasingly complicated to overturn.

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[170] For example, Renn and Marshall (2016) highlight the diversity of forces driving Energiewende policy formation, and the resulting paradoxes and unintended effects. Leiren and Reimer (2021) argue that while both domestic organizational conditions and the European Union's policy environment were influential in shifting *Energiewende* policy towards greater "market orientation" and competition in RES support, it was the political field which was most decisive.

[171] In the sense of the ability of a firm, or group of firms, to set prices by manipulating supply, demand, or both (for further discussion see Section 2.1.1.2).

7.2 Order in transition - a discussion of the British case study

The analytical perspective which I developed for this study outlines relations between differential accumulation regimes, socio-technical processes, and energy capture regimes. It does not presume to decisively and fully describe, let alone explain or predict, business-industry dynamics in energy systems under capitalism. What I did attempt is to trace possible synergies between developments in the breadth and depth of energy capture and differential accumulation strategies, claiming that these synergies take part in shaping the scope and pace of sociotechnical change in energy regimes.

The shift to fossil-fuels in British industry is a case of rapid increases in the breadth and depth of energy capture. Not only were new and energy-dense primary energy sources introduced into society, but a greater amount of primary energy was also being converted in industrial processes, and conversion efficiencies of prime movers were on the rise (see Section 3.7.1.1 and Section 4.1).[172] Towards the end of the 19th century the rampant rate of change began to decline. It was only then that the energy-core succeeded in achieving differential accumulation by leveraging the prevalent external breadth (greenfield investment) and internal depth (cost-cutting) pathways which accompanied the rapid diffusion of coal and later oil, as new primary sources, and steam engines and later turbines, as new prime movers.

It seems that initially, techno-physical changes were too rapid and widespread for one group to control and manipulate to its differential benefit. This is not to say that during the turn of the 19th century and through to the turn of the 20th century no sector, or capitalist entity[173] rose above others in terms of size (employment or output), revenues, or income. On the contrary,

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[172] The term *Primary energy* refers to energy carriers which are "directly derived from a natural source", or the environment. These could include bituminous coal, crude oil, natural gas, waste, solar irradiance, wind or waterpower to name a few examples (Olkuski et al., 2021: 503). The term *Prime movers* refers to devices that converts energy, e.g. engines, turbines, water wheels, etc.

[173] In the term *capitalist entity,* I refer to owners, firms, or groups of owners and/or firms.

this did occur in the textiles manufacturing sector (particularly in cotton manufacturing) which included some of the largest industrial employers, and in beer manufacturing, which became a bubble of huge companies in the era's terms, and of course in railways, which dominated the British stock markets during the mid-19th century (Hannah, 1983). Yet, arguably, none of these succeed in consolidating dominant capital formations in the sense that none managed to differentially shape and secure their stream of future earnings.

Moreover, throughout the 19th century, early industrial capitalists were probably not even thinking in terms of differential profit. It is likely that some conception of relative *size* did play into their calculations (in terms of control of employment, market share,[174] or output), but it was only later that *differential profit* emerged as the ultimate measure at the base of capitalist power.

Nevertheless, the energy-core's seven good years seem to have been accompanied by the development of a precursor of future price-making practices bred within the ferrous metals manufacturing business. In the following discussion I will venture into speculating over the possible mechanism which stood behind this price-making shift, speculations which I cannot confirm at the time of writing due to data limitations.

One possible way in which ferrous metals manufacturing businesses shaped differential prices is through linking wage rates to output price rates. During the first half of the 19th century average annual money wages in Britain displayed a falling and fluctuating trend. During the 1840' this trend was inverted as annual average money wages began a very slow and volatile rise, which became steadier and steeper throughout the second half of the 19th century (Feinstein, 1998: 634, Figure 1).[175] Conversely, the late 19th century (1873-1896) was a

[174] The term *market share* refers to the percentage of sales or revenues controlled by a capitalist entity.

[175] Based on the Composite Average Weekly Earnings series for Britain (1209-2016) presented in the Bank of England's *A millennium of macroeconomic data for the UK* database (BoE, 2017), I calculated that the average annual rate of change in average weekly wages in Britain between 1820-1849 was 1.43%, which increased to an average of 1.94% for the period of 1850-1879. The average rate of change in average weekly wages in Britain for

deflationary period, characterised by volatile and generally falling output prices (see Section 3.7.1.2). In this context of steadily rising wages, falling and fluctuating prices, and rapid, widespread techno-physical change, stable differential accumulation was almost impossible to achieve.

But what if businesses in one particular industry, ferrous metals manufacturing, derived a system by which to link wages to output prices, thus gaining the ability to mark-up output prices in relation to input prices, all this in the context of rising differential productivity per employee and energy input? In this case, ferrous metals manufacturing businesses would have diverged from the general business conditions and embarked on a transition from price-takers to precursor price-makers, anticipating the business practices of mature capitalism. Indeed, as further discussed in Appendix 12, only in ferrous metals manufacturing did rising output *lead* a rise in prices during the energy-core's seven good years (1894-1898), after which declining output preceded a fall in price (1899-1903).[176]

Perhaps a pathway to this development was a growing share of piece-rate pay in relation to time-rates,[177] and a general linkage of wage rates to output price rates? This could have given the ferrous metals manufacturing businesses an advantage over businesses in other industries which operated in the context of rising wages and fluctuating prices and enabled ferrous metals manufacturing businesses to mark-up output prices in direct relation to input costs. In the context of rising differential productivity (see Section 4.3.3.1, Figure 23 and Figure 25) this practice would contribute to ferrous metals manufacturing businesses' differential profit and

the period of 1880-1909 was significantly lower, 1.04%, indicating that during this period average wages were significantly less volatile.

[176] In contrast to trends in other industries and sectors, a shift occurred in ferrous metals manufacturing from price trends leading output trends between 1875-1885 to output trends leading price trends between 1885-1906. This may indicate that rather than "looking into the market", i.e., at prices, to determine output (price-taking) ferrous metals manufacturing firms began engaging in shaping prices.

[177] The term *piece-rate pay* refers to an employment system in which employees paid a fixed rate per completed item. Conversely, *time-rate pay* refers to an employment system in which employees are paid a fixed rate per unit of time. Between 1886-1906 the share of piece-rate pay in total ferrous metals manufacturing employment rose from 13% to 28% (BOT, 1893; BOT, 1907).

blaze the path to the differential pricing techniques of the 20th century. Regrettably, this line of argumentation requires further research efforts, beyond the scope of this dissertation.[178]

Nevertheless, the British case study analysis enables us to evaluate the proposition embedded in the analytical perspective developed in this dissertation (see Section 3.5) according to which transformative changes in energy capture regimes which include changes in energetic breadth and depth (i.e., primary energy use and diversity, and energy conversion efficiency and return on investment, respectively) are related to the two "roads less travelled by" in sustained *differential* accumulation, namely internal depth (cost-cutting) and external breadth (greenfield investment). While prevalent pathways, it has been argued that they are less suitable to leverage in differential accumulation (see Section 2.2.3).

The British case study was chosen as it represents a process of dual transformation which culminated during the late long 19th century:[179] the transition to fossil fuels, and the rise of industrial capitalism and the capitalist mode of power. The British case study analysis suggests a more nuanced interpretation: while the two main business pathways which accompanied the rapid transition to fossil fuels during the second half of the 19th century were external breadth and internal depth (specifically, enhanced productivity) these did not initially lead to stable differential accumulation or the emergence of dominant capital formations. It seems that it was difficult for any of the emerging capitalist entities, or clusters of these, to control and leverage the widespread and rampant techno-physical developments to achieve a stable dominant position.

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[178] While the Pearson correlation between average annual labour earnings in iron and steel production and the pig iron price index for the years 1880-1911 is extremely high (r = 0.9), this is due to the way in which Feinstein (1990: 618-619) calculated the average annual labour earnings index for iron and steel production, namely, by using "sliding scales linking wages to product prices" for most of the period. The sliding scales adjust prices to "*standard* tonnage or piece rate" (emphasis in original) and the index was further corrected for changes in the structure of iron and steel output, regional variations, and productivity. Nevertheless, there is strong qualitative support for linking wage rates to price rates in iron and steel manufacturing for this period, and partial series also support this choice (Feinstein, 1990).

[179] The term *the long 19th century* generally refers to the period between the outbreak of the French Revolution (1776) and that of WWI (1914) (Hobsbaum, 1898: 8)

Indeed, during the 1870's and 1880's external breadth and internal depth did not result in stable differential accumulation for any group because potential differential gains were offset by falling output prices and coinciding rising wages, as the workforce unionised and realized its collective bargaining power.

However, as rates of change in the breadth and depth of energy capture began to retard and techno-physical transition was tamed, control of output through *physical* breadth measures (i.e., growth in employment and use of primary energy) and *physical* depth measures (increased productivity per employee and energy input) was supplemented by a nascent price architecture. Acting as forerunners of mature capitalism's price-making technologies, the ferrous metals manufacturing businesses (as part of the energy-core) turned to pecuniary differential accumulation pathways, fulfilling a potential to control differential prices (see Section 4.3.3). It could then be argued that during the energy-core's seven good years (1894-1900), upcoming energy-core big business formations, accompanied by evolving scale in labour unions, were carried into the 20th century (with its pricing technologies and differential internal breadth-external depth cycles), on a surge of new differential pricing mechanisms which were soon to be emulated by others.[180]

The British case study analysis suggests that the maturation of the capitalist regime and of the practice of differential accumulation might have been related to business-industry-energy dynamics within the British energy-core. In this way, it makes a small contribution to the study of the complex and elusive process of transition from feudalism to capitalism during the long 19^{th} century.

It seems that though others soon followed in their path, certain energy-core businesses separated from general manufacturing business practices during the "seven good years" in a

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[180] Beginning in 1903, the rapid recovery of textiles manufacturing firms' differential business and corporate income seen Figure 15 and Figure 16 indicates that they might have been early adopters and developers of the new differential pricing techniques, but this proposition requires further research.

way that anticipated future business practices. Moreover, the maturation of global capital and its techniques marked a change in business control of industry, or the channelling of industrial potentials through business practice and logic, which perhaps has marked energy transition pathways throughout the 20th century, and into the 21st.

7.3 Conclusive discussion - a comparison

The two case studies presented in this dissertation seem to be situated at the diametrical ends of a still evolving historical process. The British case study represents an era of dual transformative change: the energy transition to fossil fuels[181] and the maturation of the capitalist mode of power (Nitzan & Bichler, 2009). The contemporary German case study, set over a century later, represents an ongoing effort to bring about a decarbonizing transition, from within the now well-established and global capitalist regime. This effort is carried out in an endeavour to mitigate the dire environmental consequences of the energy transition to fossil fuels from within the mode of power which arose alongside it, and its mature logic and technologies of control.

The energy transition to fossil fuels is a case of transformative socio-technical processes, accompanied by a rise in both breadth and depth of energy capture (see analytical perspective, Section 3.5). A decarbonizing transition, on the other hand also harbours transformative potentials, but of a different nature, as they stem from the prospective *decline* in both breadth and depth of energy capture which would accompany any substantial decarbonization of the energy system through currently feasible technologies (see Section 2.3 and Section 3.5).

[181] The wide socio-technical transition to fossil-fuels was not only a matter of the introduction of new energy-dense fossil-fuel-based primary energy sources. This transition also changed the industrial system through and through, thus changing social life at large, from reproduction, through work, transportation, consumption, welfare, governance, warfare, culture, etc. to the biosphere itself.

When comparing these historical moments, it is interesting to linger upon the role of differential pricing mechanisms in the two case studies. Differential pricing is related to external depth pathways as it involves the differential inflation of the prices of certain commodities in relation to others.[182] In this study, it appears at an incipient stage of development in the business practice of late 19th century British energy-core firms, and in an advanced form in the business strategies of dominant CEG firms in Germany (see Sections 4.5 and 5.5).

Dominant CEG firms in contemporary Germany act within well-defined and established capitalization practices. As a rule, they adhere to differential earnings as a central component of differential capitalization. They consciously act to shape and control their stream of future earnings through differential pricing (as demonstrated in Sections 5 and Section 6, in relation to the alternative tariff). As considered in Section 7.1 of the discussion, this well-established form of business control of industry is detrimental to efforts to bring about a decarbonizing and democratizing transition in the German electricity system (and, more broadly, in the Continental Europe Synchronous Area).[183]

The orchestration of differential pricing by dominant CEG firms is accompanied by declining alternative energy resource penetration rates and a course of increasing spatial and ownership centralization (see Appendix 11). Differential pricing mechanisms uncovered in the British case study analysis are different from those of contemporary CEG firms in many ways, predominantly in that they seem to be an early attempt of firms operating in energy-intensive industries to secure their position within a context of general growth, increasing energy productivity,[184] volatile output prices, and steadily rising wages. As discussed in Section 7.2, while it is probable that late 19th century businesses held a conception of relative size,

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[182] Note that even in the context of general inflationary conditions, raising prices faster than others grants a differential advantage.

[183] The Continental Europe Synchronous Area is an electric power grid which integrates electricity grids across continental Europe and facilitates electricity exchange across the area through the European Energy Exchange (EEX).

[184] Energy productivity is calculated as output per energy resource input (Steinberger & Krausmann, 2011).

differential profit was yet to be established as a basic measure of differential accumulation.[185] However, as presented in Section 4, the shift from differential techno-physical pathways (based on heterogenous physical quantities) to differential pecuniary measures (which, being pecuniary, are uniform and universal) accompanied a retardation in the growth rates of energetic breadth and depth, and a maturation of the process of socio-technical change.

Often, environmental critiques of capitalism assume that the fossil-fuel-based energy regime is a prerequisite of global capitalism as a regime preconditioned towards constant growth (Foster, et al., 2010; Nyberg & Wright, 2025). However, capitalist technique can be defined as one which "for each "need," for each productive process… develops not an object or a technique but a vast gamut of objects and techniques" (Castoriadis, 2024: 322), and capitalization is a volatile practice, which has little concern for the nature of the socio-technical phenomena being capitalized (see Section 2.2).

Keeping this in mind, the assertion that the reproduction of global capital depends on a fossil-fuelled energy system seems somewhat over-simplistic. There is no denying that the two transitions, to fossil fuels and to a regime of global capital, are *historically* linked. But does this mean that the reproduction of capitalism is contingent on the perpetuation of a fossil-fuel-based energy regime? And does this mean that a divergence from this energy regime will necessarily destabilise global capitalism? The answer is probably not as straightforward as some might argue.

In the context of global capital, the strong path-dependency of large and essential sociotechnical systems coincides with a constant flow of diverse socio-technical innovation, and at times with the emergence of path-altering potentials. Organized power might leverage both aspects of industry during transition, choosing to promote or discard new technologies,

[185] In a sense, the study is concerned precisely with the historical process of this establishment - the establishment of dominant capital and of differential capitalization as a widespread universal measure of power and its relation to the unique business-industry conditions arising from the transition to fossil fuels.

betting on reproduction or on change. In this sense dominant capital should not necessarily be viewed as materially entrenched in a specific technological setup (for example, see Foquet, 2016), but rather as acting upon an industrial terrain in which path-dependency might prove as profitable as innovation, and even, in rare cases, transformation.

In the British case study, I did try to show that the historic-specific technological, business-industry context of industrialization and the transition to steam was instrumental to the rise of the capitalist mode of power, in the sense that it gave rise to a new form of business control. But I also found that the height of socio-technical transition, in particular one based on rapid developments in the breadth of energy use and conversion efficiency, did not support the rise of dominant capital. Moreover, it was only when growth rates of energetic breadth and depth subsided that the potential to control and shape prices could be realized.

In this sense, it seems that rather than growth in energy capture, it is the ability to control the socio-technical process which is essential to the reproduction of the capitalist mode of power. As shown in the analysis of both, admittedly very different, case studies, neither rampant growth nor the threat of significant decline in the breadth and depth of energy capture provided a stable and secure basis for differential accumulation. It was only when dominant capital (or nascent dominant capital) acquired a mechanism through which to shape and control processes of socio-technical change that these could be leveraged in differential accumulation.

For this reason, I would not rush to equate the reproduction of capitalism with the perpetuation of a fossil-fuel based energy regime. While dominant capital clearly benefits from the current energy regime, which it has, for the time being, already brought under its control, global capital is perhaps more agile than it seems and will be able to capitalize a decarbonizing transition *which it can control* through strategic sabotage. In the course of the action, it will engage in shaping the scope and pace of transition, and the socio-technical potentials it might harbour.

8. Conclusion

We have reached the final chapter of this dissertation, which concludes its unfinished journey through energy transitions under capitalism.

8.1 Synopsis

To recapitulate, *Chapter Two* presented the theoretical background of the thesis, the concepts of socio-technical systems, energy regimes, social power, and transition, and how the relations between these have hitherto been explored. In this chapter I also explored possible new pathways and connections, building on a conception of social technique, or the social organization of production and reproduction, which can be traced back to the concept of *Techné* in Greek philosophy, and on the Capital as Power approach's power theory of value.

In *Chapter Three* I laid out the study's methodology, which includes an analytical perspective for the study of energy transitions under capitalism. The perspective consists of three interrelated components, namely, differential accumulation regimes, socio-technical pathways, and energy capture regimes.

Chapter Four contains the main results of the British case study analysis. In it I presented the line of inquiry which led me to conclude the following: the late long 19th century was marked by a retardation in the rapid transition to fossil fuels and the reorganisation of the industrial structure and the business form; throughout the 19th century, external breadth (greenfield investment) and internal depth (enhanced productivity) accompanied the rapid energy transition, yet these did not result in differential accumulation as falling prices offset potential differential gains; the results suggest that within the energy-core (mining and quarrying, ferrous metals manufacturing, and engineering commodities manufacturing), engineering commodities relied on differential external breadth (increasing in size faster than other industries), while ferrous metals manufacturing embarked on a differential internal depth pathway (increasing productivity per employee and energy input faster than others); during the energy-core's seven good years (1894-1900), the energy-core achieved differential accumulation, attaining new and higher levels of relative profit in the pre-WWI years (1900-1913); the results further suggest that the seven good years were marked by the energy-core, and ferrous metals manufacturing in particular, supplementing the control of output by differential pricing mechanisms (the differential shaping of output prices in relation to energy-input prices and labour income); The initial surge of energy-core firms' differential accumulation at the turn of the 20th century laid the basis for a second differential accumulation surge during the interwar years (1920-1938).

The rapid rise in breadth and depth of energy capture which characterized the energy transition to fossil-fuels was accompanied by differential external breadth (rising relative employment in engineering commodities) and differential internal depth (rising relative productivity in ferrous metals manufacturing) pathways as suggested by Hypothesis 1. Nevertheless, it seems that these pathways were insufficient in supporting differential accumulation, and only when supplemented by external depth (differential pricing mechanisms) did they result in the energy-core attaining stable higher levels of relative business income.

Chapter Five contains the quantitative German *Energiewende* case study analysis. In this chapter I presented the results which led me to uncover a hidden price-making process on the part of German conventional electricity generation firms.

The quantitative findings reveal the mechanism behind the rising differential conventional tariff (relative to the declining alternative tariff). The uncertainty of reliable electricity supply increases as a result of diminishing installed conventional capacity accompanied by increasing renewables penetration. This growing uncertainty amplifies dominant conventional electricity generation firms' effective threat to "hold back conventional supply", especially during peak load. And so, buyers (retailers and large industrial customers alike) are pushed to sign forward contracts, hedging against perceived future price hikes, and enabling conventional generators to appropriate higher revenues. I first identified this process in the rising conventional tariff and a growing income share for dominant firms.

Moreover, since 2017 dominant conventional electricity generation firms have succeeded in concentrating conventional electricity sales in their hands. This concentrated ownership group stands behind the conventional differential depth (differential pricing) process starting in 2018 and is the main beneficiary of it.

Finally, these developments don't only influence dominant conventional electricity generation firms' differential accumulation. They also affect the *Energiewende* transitional pathway. My analysis of the German federal network agency's power plant installation registry (containing over 4 million registered installations) shows that renewable energy sources development in Germany is slowing down, and all the while it is becoming increasingly socially and spatially centralized. These results support Hypothesis 2, which links external depth strategies to stagnant socio-technical pathways. It also supports the second set of hypotheses in which, without knowing the exact mechanism in advance, I suggested regulatory mechanisms would compensate dominant electricity generation firms for loss of output (e.g., subsidies, the elimination of the FinT and reversion to market-based mechanisms) and that dominant electricity firms would try to build on the techno-physical characteristics and challenges of decarbonization in their strategic sabotage efforts.

In *Chapter Six* I laid out the qualitative content analysis of in-depth interviews with key business representatives in the German electricity sector. The qualitative analysis supplements the quantitative analysis and was designed to explore processes where quantitative data was lacking. These include the details behind dominant conventional electricity generation firms' strategic sabotage of the German electricity system and differential pricing mechanisms, for example, and were instrumental to assessing the second group of hypotheses regarding the course of strategic sabotage and stagnation in decarbonization processes.

The double centralization of renewable energy sources is accompanied by a declining alternative electricity tariff and a general policy push toward market-based mechanisms. This move away from direct public subsidy made renewable energy sources development increasingly dependent on, and susceptible to, “the market,” where the power of dominant capital has reasserted conventional generation as a superior business choice.

At the same time, as dominant conventional electricity generation firms’ interests became enmeshed with the perpetuation of the reliance on dispatchable capacities, so did the possible solutions to the challenges of high renewable energy sources penetration get narrowed down to privatization and a reliance on natural gas.

How was this done? The content analysis illuminated several points: Dominant conventional electricity generation firms must traverse the thin line of strategic sabotage - not too much so as to undermine the sociotechnical system of electricity generation and the transitional pathway that they are banking on, and not too little so as to lose the leverage which affords them differential profits in the context of a constrained decarbonization process; Dominant conventional electricity generation firms actively engage in the shaping of Energiewende policy and decision-making, making the process “their own”; In doing so they strive to concentrate power and ownership over vital new and existing backup capacities (mainly gas-fired and H2-ready), which fortifies dominant conventional electricity generation firms’ ability to shape the revenue stream extracted from their control; All the while, they differentially reduce the risks associated with the uncertainty of the coal-phase-out so as to position themselves to gain from any outcome of the process.

Furthermore, following interviewees’ recurring reference to redispatching contracts, I performed a short quantitative analysis of redispatching prices, showing that these grew significantly and *disproportionately* to the rise in total redispatching volume. As redispatching prices are set in bilateral over-the-counter contracts, they can be seen as a peephole into the process of conventional electricity generation firms' differential pricing. These findings support Hypothesis 5 which anticipated the reliance of dominant electricity firms on the strategic sabotage of the techno-physical challenges of electricity grid decarbonization and deepens our understanding of the mechanisms behind it.

In *Chapter Seven* I discussed both case study analyses, each in its own, and in relation to one another. I considered the role and characteristics of price-shaping mechanisms in these two very different historical moments of the global capitalist mode of power and the fossil-fuelled energy regime. I also considered the significance of socio-technical control rather than growth in energy capture to the reproduction of capitalist power.

8.2 Theoretical contribution

In the dissertation, I take the first tentative steps towards a more systematic approach to the empirical analysis of business power, energy systems and their interfaces under capitalism. It is an attempt to peer into the indeterminable magma of industry (see Section 1 and Section 2.1.2.3),[186] or capitalist technique, and deepen our understanding of capitalist power and socio-technical change in general, and in energy systems in particular.

The determination that capitalist regimes correlate to exceptionally high rates of innovation is accepted at face value by proponents of the economic dogma and social critics alike. It is often attributed to "competition", as a feature of the capitalist order. Yet global capital is a regime characterised by exclusion, restriction, control, oligopolies, dominant capital, big business, centralized organized labour, price-making, and a host of other phenomena which do not fit

[186] Castoriadis (1994) uses the term *magma* to refer to an indeterminable form from which social forms can be extracted (institutionalized) but which is irreducible to these institutionalized forms.

with the “free market” myth. What, then, drives capitalist technique? As we do not have a concrete historical example of industry which is not intertwined with business, how can we account for the separation between the two?

In this dissertation, I did not presume to provide a totalizing, determinate, or exhaustive framework for the study of these open questions. Neither would I define industry as a magma and then presume to say anything determinate about it, which would be an oxymoron. What I did try to achieve in developing the analytical perspective was to identify possible synergies and tensions between business-led differential accumulation regimes, and changes in energy capture regimes, and their relation to socio-technical pathways. In other words, I suggested possible connections between business strategies (which are concerned with distribution and control), and changes in underlying energy-capture potentials, and how these may shape the scope and pace of socio-technical change.

Following the tentative definition of dialectics as a form of domineering translation which I suggested in Chapter Two, it could be said that in this dissertation I make a step towards a more systematic study of the institutionalization of industry and industrial change through the power-logic of business. According to the definition I gave in the literature review (see Section 2.1.2.1), domineering translation occurs between two *conflicting* social logics, so that the expression of one logic is forced through the other. Nevertheless, translation is always incomplete: it exceeds its source and at the same time cannot exhaust it. In this sense, strategic sabotage, business’ special power practice, is never airtight. In light of these arguments, can we devise a more methodical approach to the empirical analysis of energy transition under capitalism?

This question is related to another assertion, often taken at face value, according to which capitalism is contingent on the perpetuation of the fossil-fuel based energy regime in order to answer the creed of perpetual growth and the counter argument (known as decoupling) according to which growth rates can be sustained alongside decarbonization and attaining net-zero emissions (Barth, 2019). While I tend to agree with the arguments against the feasibility of absolute decoupling,[187] the study presented in this dissertation, and its results, may suggest that there is a point overlooked by this debate.

The study's results suggest that rather than growth in energy capture, it is the ability to control the socio-technical process which is essential to the reproduction of the capitalist mode of power. Neither rampant growth in energetic-productivity and the availability, diversity and energy density of primary energy resources, nor the threat of significant decline in conversion efficiency related to renewable energy sources, provided a stable and secure basis for differential accumulation. It was only when dominant capital (or nascent dominant capital in the case of late long-19th-century Britain) acquired a mechanism through which to shape and control processes of socio-technical change that these could be leveraged in differential accumulation. And so, when studying energy transition under capitalism, we should ask ourselves not only whether rates of "growth" can be sustained under changing energy capture conditions, but also how and to what extent can the energy system be controlled by business practices? As this is one of the questions which concerns capitalists in the energy field, it should concern us who study energy transition and its potentials.

Apart from these theoretical contributions to the field of energy transition studies (introducing the concept of capitalist power and technique), and to the line of CasP research into issues of energy, capital, and power (laying out the foundations for a more methodical study of business-industry dynamics), I hoped in this study to deepen our understanding of a much debated but, to my judgement, still illusive and unfathomed historical process. This historical process, to put it crudely, is the rise of capitalism as a prevailing global order.

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[187] *Coupling* refers to the proportionate co-evolution of two variables. *Decoupling* is the cessation of this trend. *Absolute decoupling* is a stronger term, meaning that the previously coupled variables now move in opposite directions. *Relative decoupling* is a weaker term, meaning that while variables still develop in direct proportion, but at different paces (Barth, 2019).

Though much has been written about the issue (Aston & Philpin, 1985; Braudel, 1992; Polanyi, 2024; Sweezey, 1954; Meiksins Wood, 1999), [188] still more is yet to be explored and understood about the transition from a feudal order impregnated by capitalist technique to a global regime of capital as power. In addition to this long-standing preoccupation with the transition from feudalism to capitalism, a recent line of inquiry studies the connection between the rise of capitalism and the energy transition to fossil fuels and related industries (DiMuzio & Dow, 2017; Malm, 2013; Satia, 2018).

Though I do not offer a comprehensive answer to these questions, the British case study results do reveal a hitherto undiscussed aspect of the relation between the specific business-industry setup of the transition to fossil fuels and the shift towards the all-pervading practice of differential capitalization (Nitzan & Bichler, 2009). In the dissertation I show how nascent price-making mechanisms developed within the British energy-core industries and drove them to higher levels of relative profit in what is arguably one of the earliest stable processes of differential accumulation in Britain. While these business pathways were soon to be emulated, it was within the energy-core, and specifically ferrous metals manufacturing which controlled pivotal energy-intensive intermediate goods, that they seem first to appear.

In addition, the results of the German *Energiewende* case study demonstrate how allegedly path-altering processes, harbouring the potentials for democratization and decentralization of the electricity system, get tied up with the interests of dominant capital, reshaped and restricted through strategic sabotage.

[188] For example, *The Brenner debate* is a discussion within Marxist historiography regarding the origins of capitalism (for further reading see Aston and Philpin (1985), which concentrate the major contributions to this debate).

8.3 Methodological contribution

The main methodological contribution of this dissertation lies in the development and employment of new conceptual tools for the empirical study of capitalist power in transitioning energy systems. The tools combine techno-physical and pecuniary analysis to study the ways in which dominant firms (or their precursors) attempt to leverage physical changes to increase their sectoral control, and the implications this might have for transitional pathways. I contend that to understand social power in energy transition, its pace, scope, and limits, we must study all three aspects of the business-industry-regulation triangle. Hence, we should use differential pecuniary data to represent business management, physical data to represent industrial changes, and policy analysis to understand the regulatory framework through which public policy directs industrial change.

In light of this, I developed two sets of conceptual tools, one for each case study and in accordance with its unique historical context. For the British case study, I used an integrated study of three analytical categories as the basis for an investigation of the coupled changes in energy capture systems, and social power accumulation regimes. These categories include physical energy capture measures, differential pecuniary measures, and what I term energy-core business-industry measures.

It is in the last category that the main methodological innovation lies. The measures in this category are based on Bichler and Nitzan's (2002) conception of differential profit. I constructed two sets of measures: the first is based on *heterogenous* physical quantities and the second on *universal* pecuniary representations. I first used employees as the basic unit of organization to study general differential breadth and depth pathways; I then used output and energy-based measures to study *techno-physical* breadth and depth pathways; and finally, I studied differential pecuniary measures, which represent differential external depth (differential pricing) pathways. This division between physical-based measures and pecuniary measures enabled me to differentiate between external breadth and internal depth (represented by physical-based output and energy measures), and external depth (represented by differential pecuniary measures).

For the German *Energiewende* case study I developed four sets of measures which combine physical, financial, and accounting records data: The first set of measures studies differential external depth in the context of a transitioning electricity sector by comparing the alternative to the conventional tariff; The second measure studies the degree effective control that conventional electricity generation firms hold over the electricity system in the context of decarbonization processes; The third set of measures traces the reliance of conventional electricity generation firms on future contract, and hence on a perceived risk to reliable supply; The fourth and final measure is that of the centralization trends in the control of conventional electricity generation. The integrated study of these four conceptual tools allows for the study of business-industry dynamics and transitional pathways in the specific context of renewable-energy-resources-based decarbonization.

8.4 Empirical contributions

Finally, the study also offers the following empirical contributions: 1. I calculated several series of historical British national accounts estimations which have hitherto been unavailable. The most outstanding of these are business and corporate income estimates by industry (1881-1913), GVA estimations by industry (1920-1938), and profit margin estimations by industry (1920-1938); 2. I calculated alternative series to the Lewis/Feinstein Engineering output and GVA which I argue to be more accurate; 3. As part of the *Energiewende* case study analysis I used aggregate accounting records to calculate separate alternative and conventional tariff series (2011-2021) which could not be identified using electricity exchange prices alone. The 'demand side' approach to the construction of the tariff (see Appendix 5) enabled the separation between the alternative and conventional tariff; and 4. Using big data analysis I aggregated the complete Marktstammdatenregister (MaStR) power plant registry (which contains over four million entries) according to ownership and techno-physical categories. The aggregation according to these categories enables an analysis of spatial, techno-physical, and ownership structure trends which would be impossible to achieve if working with the raw dataset alone.

8.5 Future research

The strengths and weaknesses of this dissertation stem from the same tensions which propelled it forward. I will hereby name two of these tensions. On the one hand, in this dissertation I make tentative steps towards addressing broad theoretical issues which have led me to uncharted territories, even within well-trodden fields such as the British industrial revolution, rather than filling a narrow gap within a fossilized theoretical and methodological setup.[189] These broad theoretical questions include the empirical study of industry within the capitalist order, the definition of dialectical business-industry relations as a form of *domineering translation*, and methods for empirically studying these relations, among others.

On the other hand, the broad scope of these questions has proven too broad to fully address within the framework of a PhD dissertation, and so, many ideas are only preliminarily explored and beg further research and development. Predominant among these ideas are the project of developing a systematic approach to the study of socio-technical change and capitalist power, and the definition of dialectic dynamics as a form of domineering translation.

This point of tension leads to another, which arises from the stark differences between the two case studies chosen for this research. On the one hand the two case studies represent pivotal developments within the ongoing spiralling process of the rise and reproduction of the capitalist

[189] In the sense that narrow scope of filling-the-gap efforts, and their reliance on the perpetuation of entrenched methods and assumptions, usually end up reinforcing already existing theoretical and methodological constructs rather than opening up new pathways to understanding, and even identifying, social phenomena.

mode of power, and its concurrent fossil-fuel based energy regime. And so, the study focuses on the period of transition in which the two regimes were established, and on the period in which the threats associated with climate change processes induced by the fossil-fuel-based energy regime are attempted to be tackled from within the prevailing capitalist order. In this sense, it is illuminating to study them against each other.

On the other hand, the historical differences between the two cases are so wide, the context and the details so distinct, that the comparison between them can only be undertaken at a very general level. It could also be said that the analysis of each case study could have been undertaken in itself, and thus developed much further, but if such a decision were made, the comparative features of the dissertation would be lost. The analysis of the German *Energiewende* case study in particular is instrumental to informing an understanding of the challenges, pitfalls, and tensions of other unfolding decarbonization processes worldwide (albeit obvious differences), and the struggle for energy democratization in the context of decarbonization processes within a regime of global capital.

Acknowledging the interwoven strengths and weaknesses of this dissertation leads us to identifying possible future research pathways, a few of which I will present henceforth.

Within the two case studies presented in this manuscript plenty of work remains to be done. The British case study would benefit from further empirical efforts, especially in areas where data was lacking. The suggestion that ferrous metals manufacturing businesses linked piece-time-rates to output prices and thus separated from businesses in other industries at the time by embarking on a novel price-making path requires further research. If this is indeed the case, it would deepen our understanding of the transition to a system of capital as power.

The study of the mechanisms behind the second phase of energy-core differential accumulation during the interwar years could be empirically pursued, as well as the longer-term patterns identified in Appendix 8.

The *Energiewende* case study deals with a still unfolding process. The development of the process could be traced in as it unravels, in accordance with the line of inquiry initiated in this dissertation. The analytical prism could also be enlarged to include the Continental Europe Synchronous Area, or even global transitional dynamics, as the dominant conventional electricity generation firms which I studied are all multi-national corporations which operate outside of Germany as well. It would also be interesting to use the study's conceptual tools to analyse electrical grid decarbonization processes elsewhere.

Apart from this, it would be interesting to use the research framework to study other processes of less conspicuous socio-technical change and stagnation, for example the shift to AC technology in electricity transmission, the emergence of fluorescent lighting, the unfulfilled potential of early 20th century electrical vehicles and storage batteries, the development of nuclear power, green-hydrogen, and more.

Finally, from a theoretical standpoint, the attempt to develop a more systematic approach to the empirical analysis of capitalist forms of power, socio-technical systems, and transitional pathways is far from complete. I hope that as more empirical studies of the relations between these three aspects of reproduction and change under capitalism are undertaken, so will our theoretical understanding of them deepen, along with our capacity to act upon them effectively.

Appendix

Appendix 1: Electricity Generation Categorisation Alternatives

Table 23: Socio-technical Electricity Generation categorization.[190]

Category	***Resource/Technology***	***Measures***
EEG Eligible	Onshore Wind Offshore Wind Solar PV Geothermal Biomass	1. Renewable Total Net Generation 2. Renewable Installed Capacity 3. Renewable Revenues (million€) 4. Renewable Revenues per Energy Generation (€/MWh)
Non-EEG Eligible	Hard Coal Lignite Natural Gas Nuclear Oil Waste Hydro (stored)[191] Hydro (run-of-river) Other	1. Conventional Total Net Generation 2. Conventional Installed Capacity 3. Conventional Revenues (million€) 4. Conventional Revenues per Energy Generation (€/MWh)
Variable	Onshore Wind Offshore Wind Solar PV	

[190] Light grey alternatives to the AEG category, while the darker shade of grey represents alternatives to the CEG category.

[191] Though hydropower is included as EEG eligible in the Renewable Energy Sources Act 2017, section 40 delimits restrictions to this, and the BnetzA Monitoring Report 2022 implies that a considerable amount of Hydropower is unsubsidised (BnetzA, 2022:97).

Table 23: Socio-technical Electricity Generation categorization - continued

Non-Variable	Hard Coal Lignite Natural Gas Nuclear Oil Hydro (stored) Hydro (run-of-river) Waste Geothermal Biomass Other

Table 24: Germany Datastream Conventional and Alternative Electricity Indices

Index	***Firms***
Germany datastream alternative electricity (GERMANY.DS.Alt..Electricity)	ENCAVIS PNE ENERGIEKONTOR 2G Energy
Germany datastream conventional electricity (GERMANY.DS.Conv..Electricity)	EnBW Energie Baden-Wutenburg Lecwerke (E.ON subsidiary) MVV Energie

Appendix 2: Dominant electricity generation firms and their subsidiaries

Table 25: Dominant Electricity Generation Firm Categorization

Category	Firm	Subsidiary
Dominant	RWE	RWE Generation SE RWE Power AG Grosskraftwerk Mannheim AG Schluchseewerk Aktiengesellschaft
	EnBWBundeskartellamt	EnBW Kernkraft GmbH Stadtwerke Düsseldorf AG Kernkraftwerk Obrigheim GmbH Obere Donau Kraftwerke AG
	E.ON UNIPER	Innogy SE E.ON Kernkraft GmbH Preussen Elektra GmbH Bayerische Elektrizitätswerke GmbH Gemeinschaftskraftwerk Irsching GmbH Gemeinschaftskraftwerk Kiel GmbH Gemeinschaftskraftwerk Veltheim GmbH GHD Bayernwerk Natur GmbH & Co. KG Müllheizkraftwerk Rothensee GmbH Peissenberger Kraftwerksgesellschaft mbH Peißenberger Wärmegesellschaft mbH

Table 25: Dominant Electricity Generation Firm Categorization - continued

Dominant	Vattenfall Europe	Vattenfall Wärme Berlin AG Vattenfall Heizkraftwerk Moorburg GmbH Vattenfall Wasserkraft GmbH Vattenfall Europe Wärme AG Vattenfall Europe Nuclear Energy GmbH Vattenfall Hamburg Wärme GmbH Vattenfall Europe New Energy Ecopower GmbH
	LEAG	Lausitz Energie Kraftwerke AG|
Non-Dominant	All other firms in conventional power generation	

Appendix 3: Data Source by Category

Table 26: Data Sources for Pecuniary and Spatio-physical data by category and variable

Category	***Data***	***Data Source***
EEG Eligible	Total Net Generation 2000-2021	BnetzA Monitoring Reports (2006-2022)
	Total Net Nominal Generation Capacity 2000-2021	BnetzA Monitoring Reports (2006-2022)
	Total EEG Remuneration (Market Value) (2000-2021)	BMWK (EEG In Zahlen)
	Total EEG Payments (2000-2021)	BnetzA Monitoring Reports (2006-2022)
	Total EEG Market Revenue (2000-2021)	BMWK (EEG In Zahlen)
Non-EEG Eligible	Total Net Generation 2000-2021	BnetzA Monitoring Reports (2006-2022)
	Total Net Nominal Generation Capacity 2000-2021	BnetzA Monitoring Reports (2006-2022)
	Fuel Use in Electricity Generation	AGEB
	Revenue from Generation	DeStatis
	Fuel Price for Electricity Generators	AGEB
Variable	Variable Energy Resources penetration	BMWK (EEG In Zahlen)
Non-Variable	Non variable generation during peak load	Statista, Fraunhoffer

Appendix 4: A detailed explanation of British case study analysis quantitative measures

1. Category I: Physical energy capture measures

Exergy, Useful Work, and Conversion Efficiency

For the period of 1900-2000 I used annual estimates of exergy, useful work, and energy conversion efficiency in the UK.

The term *exergy* refers to the "useful component of energy", which can perform useful work (Ayers & Warr, 2009: XX). While the First Law of Thermodynamics states that energy is a conserved quantity, the Second Law states that energy transformation processes reduce the amount of energy available to perform useful work (exergy) in a physical entity or system, while increasing the measure of the non-useful energy component (entropy). In this sense, when relating to a system's potential to perform useful work, we are referring to its exergy content.

The term *useful work* is defined as "the sum total of all types of physical work by animals, prime movers and heat transfer systems" (Ayers & Warr, 2005: 181).

The term *energy conversion efficiency* is defined as the ratio of useful work (output) to energy input of a process, or, in terms of exergy, the ratio of the actual useful work performed by a system (output) to its potential to perform useful work (exergy input) (Ayers & Warr, 2009).

In the absence of data on exergy, useful work, and energy conversion efficiency in the UK prior to 1900, I used estimations of UK coal output, installed steam engine capacity in UK industry, and maximum steam engine conversion efficiency as proxies for the breadth and depth of societal energy capture for the period of 1700-1920.

In analysing the development of societal energy capture breadth and depth, I was most interested in studying the rate of change, magnitude and trajectory of these measures.

Thus, for the years 1700-1920 (the period changing in accordance with data limitations) I used the following physical measures:

1. Primary energy capture in the transition to fossil fuels were measured as *coal output per capita*, a measure of energy capture breadth. The measure is calculated by dividing total coal output by population size.

$$CO\ per\ capita\ = \frac{CO}{P}$$

Equation 4: Coal output per capita

Here, *CO* is Coal Output (tonnes), and *P* is population.

Seeing as I was interested in the annual change in coal output per capita, and in the absence of annual data, I calculated the geometric mean of the rate of change between every two data points. Thus, the *average annual geometric rate of change*, also known as *Compound Annual Growth Rate (CAGR)*, was calculated using the following formula:

$$CAGR = (\frac{Vfinal}{Vbegin})^{\frac{1}{t}} - 1$$

Equation 5: Compound Annual Growth Rate (CAGR)

Where *CAGR* is compound annual growth rate, *V* is Value, and *t* is time.

2. Where data was available, I used *energy conversion efficiency* and *exergy efficiency* to measure energy capture depth. Exergy efficiency is calculated as the ratio of useful

work and exergy (Ayers & Warr, 2005). For the period preceding 1900 I used the maximum conversion efficiency of steam engines. It should be noted that this is a very rough proxy of the development of the depth of societal energy capture, as it disregards changes in the efficiency of primary energy capture (EROI). It is also clear that, even in relation to the conversion of primary sources, only a fraction of installed prime mover capacity in the UK during 19th century consisted of steam engines, it cannot be assumed that these were employed at full capacity, and only a fraction of installed steam engine capacity consisted of steam engines with the maximal periodic conversion efficiency. Nevertheless, prior to the 20th century this measure can act as proxy to the exergy efficiency potentials of industries which became gradually reliant on coal as primary energy source and steam engines as prime movers during the 19th century.

In the absence of annual data for installed steam engine capacity and maximum steam engine efficiency, I calculated the geometric mean of their periodic rates of change, as explained in detail for coal output per capita.

3. UK steel and pig iron production, and their rates of change – These two measures reflect the growth of energy-core industries by concentrating on the compound annual growth rates of pig iron (a basic energy-intensive intermediate good in the energy-core production chain), and steel (a higher-level energy-intensive intermediate good in the energy-core production chain).

4. Installed steam engine capacity by industry – this is a physical industrial measure representing differential developments in industrial steam power deployment. It reflects changes in the distribution of installed steam power shares.

2. Category II: Energy-core business-industry measures

1. The ratio of total bond par value to total loans and advances from UK banks is used to measure changes in financing patterns of British firms.

$$Bond\ Loan\ ratio = \frac{Total\ bond\ par\ value}{Total\ loans\ and\ advances}$$

Equation 6: Bond to loan ratio

The measure aggregates the total pecuniary par value of bonds listed on the LSE and other British stock markets and divides it by the total pecuniary value of loans and advances from UK banks, the numerator representing stock-market sourced financing, and the denominator representing financing through bank loans to industry.

2. The *Buy to Build indicator* is expressed as the ratio of the pecuniary value of mergers and acquisitions (M&A) to gross fixed capital formation (GFCF), or as the value of M&A as a percentage of GFCF. Bichler and Nitzan (2009: 338) understand the indicator to roughly correspond to "the ratio between internal and external breadth" strategies, i.e., mergers and acquisitions and greenfield investment, respectively.

National accounts terms and measures

3. I use Gross Value Added[192] (GVA) by industry (in constant 1907 prices and current prices) to study the differential development of sectors. Following a procedure similar to the one Jeffrey and Walters (1956:28) use in calculating nominal industrial output series, this measure was obtained by as follows: I multiplied Lewis's (1967:118) UK

[192] *Gross Value Added* is a pecuniary measure representing the total value of goods and services produced in a defined area or industry over a defined period, over and above the costs of goods, and deducting the value of intermediate inputs used in production processes. It is the primary component of GDP, calculated from the output side, to which taxes are added and from which subsidies are deducted (Walton & Dey-Chowdhury, 2018).

manufacturing and mining GDP estimation for 1907 by his list of industrial weights divided by 100 for the same year (Lewis, 1967: 86) to obtain GDP by industry for 1907. I then multiplied the results by Feinstein's (1972: T111) index of industrial production by main orders (100 = 1913) divided by 100 / 1907 value. To obtain nominal values I multiplied the results by the relative price index series obtained from British Board of Trade (1903) publications, and from Mitchell, 1988: 728-34. Table 5. The Board of Trade series supply a more detailed disaggregation (e.g., separate series for coal, pig iron, other metals, while Mitchell (1988) supplies a combined series for coal and metals), yet it ends in 1902 while Mitchell's (1988) series continue to 1913. I used the rate of change on Mitchell's series to complete the Board of Trade's disaggregate series to 1913. Feinstein (1972: 1) uses net output and value added interchangeably. Note that, finding the Lewis/Feinstein calculation of the engineering series problematic, I calculated a new series for this sector, as explained in detail in Appendix 4.4.

In order to equalize Lewis' industrial weights and Feinstein's industrial main orders categories a summation of Lewis' categories was performed as presented in Table 27:

Table 27: Feinstein's and Lewis' industrial categories

Feinstein, 1972	***Lewis, 1967***
Mining and Quarrying	Coal + Iron ore + Other mining
Textiles, Leather and Clothing	Cotton yarn + Cotton cloth + Woollen yarn + Woollen cloth + Silk yarn + Silk cloth + Jute + Hemp + Linen yarn + Linen cloth + Leather + Leather goods + Clothing + Textile finishing
Textiles	Cotton yarn + Cotton cloth + Woollen yarn + Woollen cloth + Silk yarn + Silk cloth + Jute + Hemp + Linen yarn + Linen cloth
Metal Manufacturing	Iron and steel + non-ferrous metals
Ferrous Metals Manufacturing	Iron and steel
Food, Drink and Tobacco	Flour + Bread + Meat + Confectionery + Sugar + Beer + Malt + Spirits + Tobacco + Vegetable oils + Food manufacturing
Paper and Printing	Printing + Paper
Engineering and allied industries	Iron and steel products + Shipbuilding + Motor vehicles
Engineering	Iron and steel products
Total Manufacturing	Total (100) - Mining and quarrying - Gas - Electricity

4. The second set of measures based on national accounts data are business income by industry, corporate income by industry, and the differential business and corporate incomes.
    a. Business income by industry is a rough proxy of the total revenues of employers and the self-employed, presented differentially, by industry. It is calculated by subtracting an estimation of total labour income by industry from industrial GVA. Labour income by industry is calculated as follows: 1. I calculated the average annual full-employment earnings per employee by industry by multiplying Feinstein's (1990: 604, 608-611) average annual full-employment

earnings for 1911 by his Index of average full-time money earnings by sector, 1880-1913 (1911 = 100), and his Index of average full-time earnings, by manufacturing industry, 1880-1913 (1911 = 100), divided by 100; 2. I then used the Band of England's (2017) *A millennium of macroeconomic data* dataset (Table A53. Employment by industry, 000s of jobs.), and Feinstein's (1990) workforce estimations, and the Census of Population, England and Wales, 1911, General report with appendices: appendix C, TABLE 65: ENGLAND AND WALES— OCCUPATIONS (Condensed List) of PERSONS, MALES, and FEMALES, p. 274-80, to achieve annual estimations of workforce by industry. In cases where data was only available by decade, I used a linear interpolation to estimate missing data points; 3. Finally, I multiplied annual average full-employment money earnings by industry by the annual estimations of workforce by industry, to achieve the estimated annual labour income by industry. Below is the formula for calculating business income:

$$BI = GVA - LI = GVA - ALE * Employees$$

Equation 7: Business income

Where *BI* is Business income (£), *GVA* is Gross Value Added (£), *LI* is Labour income (£), *ALE* is average labour earnings (£), and *Employees* in the number of employees.

b. Corporate income by industry is a rough proxy of the total revenues of employers (firms), presented differentially, by industry. It is calculated by multiplying business income by the share of trading profit in non-farm business income (which is composed of trading profits and self-employment profit and is calculated by deducting labour income from non-farm GDP, calculated from the income side).

I calculated the share of trading profit in business income using Solomou & Thomas' (2019: 49-50) breakdown of Gross Trading Profits and Self-Employment income, as follows:

$$share\ GTP\ in\ BI\ = \frac{GTP}{GTP\ +\ SEI}$$

Equation 8: Share of corporate income in business income

Here, *GTP* in Gross Trading Profits, *BI* is Business Income, and *SEI* is Self-Employment Income.

c. The differential business and corporate income measures are calculated as a quotient of industry-specific business/corporate income and total mining and manufacturing business income. As follows:

$$Diff.business\ income = \frac{industry\ specific\ BI}{Total\ m\&m\ BI}$$

Equation 9: Differential business income

$$Diff.corporate\ income = \frac{industry\ specific\ BI * share\ GTP\ in\ BI}{Total\ m\&m\ BI}$$

Equation 10: Differential corporate income

Here, *BI* is Business Income, *m&m* is mining and manufacturing and *Share GTP in BI* is share of Gross Trading Profits in Business Income.

5. Energy-core's share in total LSE capitalization – Total capitalization is the total value of long-term debt and equity (e.g., bonds and shares) which comprise a firm's capital structure. This measure represents the share of the total nominal value of energy-core

firms' securities in the total nominal value of securities listed on the London Stock Exchange (LSE). A rise in the share of energy-core firms' total capitalization in the total capitalization of securities indicates that these industries are beating the general growth rate of capital on the LSE. Due to data restrictions, the *energy-core industries* category consists of a slightly different composition. The engineering commodities manufacturing industries are not represented, and three main industries make up the category: coal, iron, and steel (representing coal mining and ferrous metal manufacturing), gas, and shipping for the period of 1883-1913, adding the new industries of oil, nitrates, and electricity as they appeared in 1913. The addition of new industries is mentioned in the data and figures.

6. Big energy-core firms' differential performance - I would have liked to have had a measure of differential business income for dominant energy-core firms (as opposed to all total energy-core business income) but could not construct one due to data limitations. Hence, I used the nominal value of energy-intensive industries listed on the LSE as a rough proxy for the trajectory and relative magnitude of dominant energy-core firms' income, assuming that a significant portion of them was listed on the LSE, while smaller firms were not. Foreman-Peck and Hannah (2024: 3) note that Large "public corporations in British manufacturing increased in number and mean sizes at the expense of partnerships… attained higher capital–labour ratios than other types of business… and achieved stronger employment growth… relative to partnerships, private corporations, and sole traders".

   The limited liability form was applied early and predominantly to energy-intensive industries, and the large firms resulting from the late 19th century M&A waves were listed on the LSE (Cheffins, 2008; Payne, 1965; Shannon, 1933). Thus, the measure is calculated as the quotient of total energy-core capitalization to total m&m business income and is used as a tentative proxy of large energy-core firms' performance. It should be stated that this measure must be interpreted with care as it divides *capitalization* by *income*. While current earnings are a basic component of the capitalization formula, capitalization, as an expression of *expected future* earnings discounted to current value, is also dependent of discount rate, hype, and risk perceptions. Thus, it does not reflect *present* income, or *present performance* as such, but rather the *expectations* regarding *future performance*, as well as the discount rate. Nevertheless, current earnings are a major component of future expectations.

7. Differential trading profits is a measure of profit shares which I used in studying the period 1920-1938 when data was available. The measure is calculated as the quotient of a group of industries' gross trading profits and total non-agricultural trading profits (including all sectors of the economy save for agriculture). The measures for the years 1920-1938 represent a wide definition of the energy-core (which we were unable to achieve for the pre-WWI years due to data constraints). For this period the energy-core group contains mining and quarrying, energy-intensive manufacturing (i.e., metals manufacturing, engineering commodities, shipbuilding, electrical goods, vehicles, chemicals, and building materials), and energy-intensive utilities (i.e., electricity and gas). These industries represent the second phase of energy-core dominant capital consolidation.

8. In completion to the previous measure of profit shares, this measure is one of profit margins. I calculated the approximated profit margins by dividing industrial trading profits by total non-agricultural GVA. The total non-agricultural GVA is used as the denominator to account for all inputs in the production process (save for imported inputs). I calculated GVA by adding trading profits to income from employment, as below:

$$Profit\ margin\ proxy = \frac{industry\ specific\ TP}{Total\ non\ agricultural\ TP + total\ non\ agricultural\ EI}$$

Equation 11: Profit margin estimate

Where *TP* is Trading Profits and *EI* is Employment Income.

3. Category III: Differential pecuniary measures – financial and national accounts data

1. The break-down of Bichler and Nitzan's (2002) differential profit measure to breadth and depth is presented in detail in Section 2.2.3. I used the following versions:

$$Differential\ Breadth = \frac{Employees_{Industry\ specific}}{Total\ Mining\ \&\ Manufacturing\ employees}$$

Equation 12: Differential breadth

$$Differential\ Depth = \frac{\left(\frac{Business\ Income}{Employee}\right)_{Industry-specific}}{\left(\frac{Business\ Income}{Employee}\right)_{Mining\ \&\ Manufacturing}}$$

Equation 13: Differential depth

2. Output per employee was calculated by converting the number of employees to an index and dividing Feinstein's (1972; T111, T114) output index by the employee index. Number of employees by industry were interpolated from Feinstein, 1990: 604, 608-611. In the case of engineering commodities, number of employees was aggregated and interpolated from the UK Census of Population, 1911: Appendix C, Table 64: Occupations of Males and Females, p. 264-5, according to categories from the UK Census of Production, 1907: Preliminary Tables, part II: 7. Engineering Factories (including Electrical Engineering).

Relative energetic breadth was calculated as the share of coal used in ferrous metals manufacturing, and in mining and quarrying in the total industrial use of coal in production processes.

The following set of measures of income per basic unit of input, energetic breadth and depth are discussed and presented at length in the main body of the text (Section 3.10.1.1), and are brought here in formulaic form only:

a. Income per basic unit of input:

$$Income\ per\ ton\ of\ Pig\ Iron = \frac{Ferrous\ metals\ manufacturing\ Business\ Income}{Pig\ Iron\ production}$$

Equation 14: Income per ton of pig iron

Where business income is denominated in pounds, and pig iron production in tons.

a. Energetic breadth:

$$Energetic\ breadth = Total\ coal\ use\ in\ Ferrous\ Metals\ manufacturing\ (tons)$$

Equation 15: Energetic breadth in ferrous metal manufacturing

b. Energetic depth:

$$Energetic\ depth = \frac{Coal\ use\ in\ ferrous\ metals\ manufacturing}{Pig\ Iron\ production}$$

Equation 16: Energetic depth in ferrous metal manufacturing

Another measure used for energetic breadth was output per coal use (calculated for mining and quarrying and ferrous metals manufacturing). This index was derived by dividing Feinstein's (1972: T111, T114) output indices by coal use in iron and steel production and mines and collieries from Kennedy, 2020: Appendix 5, supporting data for Figure 2.

3. The following group of differential pecuniary measures was used to study differential external depth:

$$Differential\ Price = \frac{Price\ index_1}{Price\ index_{general}}$$

Equation 17: Differential price

This measure represents differential pricing. Price indices were obtained from: Great Britain Board of Trade (department of labour statistics), 1915: 88-89, Index Numbers for Wholesale Prices: All Groups and Index Numbers for Wholesale Prices: coal and metals.

The two final measures explore a possible source for the rise in energy-core business income per pig iron production: differential pricing.

The first compares pig iron (output) prices to coal (energetic input) prices by dividing the two price indices:

$$Pig\ iron\ to\ coal\ price\ ratio = \frac{Pig\ Iron\ Price\ Index}{Coal\ Price\ Index}$$

Equation 18: Pig iron to coal price ratio

The second compares pig iron (output) prices to labour income in iron and steel manufacturing (input):

$$Ferrous\ metals\ price\ to\ wage\ ratio = \frac{Pig\ Iron\ Price\ Index}{Annual\ Average\ Wage\ in\ Iron\ \&\ Steel\ Index}$$

Equation 19: Ferrous metals price to wage ratio

4. Constructing the new engineering commodities output index

This appendix explains the method I used to calculate an alternative engineering commodities output index. Feinstein (1988: 262, 294-295) based his engineering output index on a physical index of iron and steel output for domestic use which he adjusted in two ways for quality changes. First, by adding an arbitrary annual increase of 0.5%, he accounted for changes in the quality of manufactured iron and steel (as major inputs in engineering commodities manufacturing), which are assumed to lead to changes in the quality of engineering commodities. Secondly, he used the engineering average annual wage index and the iron and steel price index (both with equal weights) to account for changes in the quality of the engineering commodities themselves (other than quality changes which result from the better physical inputs). Paradoxically, the engineering price index is also based on the iron and steel price index and the engineering average annual wage index (with equal weights) (Feinstein, 1988a: 262, 432). And so, when converting the engineering commodities GVA in constant pounds series obtained from the engineering output index to nominal prices, one would be using the same price and annual wage indices twice, once as a proxy for quality changes in engineering commodities, and then (cancelling the former effect), as a proxy for changes in the nominal prices of engineering commodities.

This procedure seems to me methodologically unsound. Instead, I used the iron and steel for domestic output index use (from Lewis (1978: 253) where it is termed the iron and steel products index and already includes an annual growth of 0.5% to account for changes in ferrous metals quality) *and* an index of the number of employees in engineering commodities manufacturing, both with equal weights. Thus, the physical proxy for engineering commodities output is based on changes in the two core inputs to the manufacturing process - iron and steel intermediate goods, and labour. Following Feinstein (1988: 294), the number of employees index was adjusted for changes in labour productivity by assuming an arbitrary annual increase of 0.5%. This produced an engineering commodities output index based on iron and steel production and the engineering commodities workforce.

In order to reflate the GVA series in constant prices derived from the output series, I used Feinstein's (1990) engineering annual average wage index alone (which I reverse adjusted for change in labour productivity by calculating an annual reduction of 0.5% so that the arbitrary increase in labour productivity would not be twice accounted for). I chose to use only the engineering annual average wage index, and not the iron and steel price index, as changes in iron and steel prices do not necessarily reflect changes in the final product prices of engineering commodities. Hence, to calculate the output index I used only physical indices (iron and steel output and number of employees), and to account for changes in prices I used only a pecuniary-based index (average annual wages).

The formula for calculating the alternative engineering commodities output index is presented below:

$$\begin{aligned} &\mathit{Engineering\ commodities\ output\ index} \\ &\quad = 0.5 \cdot \mathit{Iron\ and\ steel\ products\ output\ index} + 0.5 \\ &\quad \cdot \mathit{Adjusted\ engineering\ commodities\ employees\ index} \end{aligned}$$

Equation 20: Alternative engineering commodities output index

Appendix 5: A detailed explanation of the German *Energiewende* case study quantitative measures

1. The differential tariff

The first set of measures study the basic question: how much do businesses receive for a unit of generated electricity? The measure comes in two forms:

1. revenue per energy unit (€/MWh)

2. a rough proxy of gross profit per energy unit (€/MWh, taking in account average variable fuel costs).

The measure enables analysis of differential patterns as it expresses the *depth* of accumulation based on energy units. I use it to evaluate the conventional electricity and alternative electricity tariffs, and their ratio.

The electricity tariff is the price per unit of electricity. It can be expressed as:

$$Electricity\ Tariff\ = \frac{total\ electricity\ generation\ revenue}{total\ net\ electricity\ generation}$$

Equation 21: Electricity Tariff

For the Conventional Electricity Tariff, I apply the same calculation only using conventional electricity revenue and conventional electricity generation. These variables are calculated as follows:

$$\begin{aligned}&\mathit{Conventional\ Generation\ Revenue}\\&\qquad = \mathit{Total\ Generation\ Revenue} - \mathit{Renewable\ Market\ Revenue}\end{aligned}$$

Equation 22: Conventional Electricity Generation Revenue

$$\mathit{Conventional\ Electricity\ Generation} = \mathit{Total\ Net\ Generation} - \mathit{Renewable\ Generation}$$

Equation 23: Conventional Electricity Generation

I use EEG Market Revenue (i.e. revenue obtained through sales on the market rather than subsidy payments) to express renewable market revenue, and EEG eligible[193] electricity generation to express renewable generation.

Thus, the conventional electricity tariff (Equation 24) is calculated as:

$$\mathit{Conv\ Tariff} = \frac{convGR}{CEG} = \frac{TGR - EEGMR}{TNG - EEGEG}$$

Equation 24: Conventional Electricity Tariff

Where *Conv Tariff* is Conventional Tariff (€/MWh), *convGR* is conventional generation revenue (million€), *CEG* is conventional energy generation (TWh), *TGR* is total generation revenue (million€), *EEGMR* is total EEG Market Revenue (million€), *TNG* is total net generation (TWh), and *EEGEG* is EEG eligible electricity generation (TWh).

By subtracting total EEG remuneration from total generation revenue, I obtain conventional generation revenue. Conventional energy generation is expressed as the difference between

[193] EEG eligible refers to electricity generation installations eligible for payment under the Renewable Energy Resource Act (EEG).

total net generation and EEG eligible generation. The quotient of the two results expresses the conventional tariff. For further detail on how this measure is estimated within given data constraints, see Appendix 5.5.

The alternative electricity tariff (Equation 25) is defined as:

$$Alt\ Tariff\ = \frac{EEGR}{EEGEG}$$

Equation 25: Alternative Electricity Tariff

Where *Alt Tariff* is Alternative electricity Tariff, *EEGR* is total EEG Remuneration (million€) i.e. EEG market revenue + EEG subsidy payments, and *EEGEG* is EEG eligible electricity generation (TWh).

The gross profit proxy is estimated by subtracting fuel costs, which are a main variable cost component in electricity generation, from conventional generation revenue.

Fuel costs in electricity generation are calculated as follows:

$$Fuel\ Costs\ = (NGp\ \cdot\ NGu) + (HCp\ \cdot\ HCu) + (Lp\ \cdot\ Lu)$$

Equation 26: Electricity Generation Fuel Costs

Where *NGp* is natural gas price for electricity generation (€/t SKE), *NGu* is natural gas use in electricity generation (t SKE), *HCp* is hard coal price for electricity generation (€/t SKE), *HCu* is hard coal use in electricity generation (t SKE), *Lp* is lignite price for electricity generation (€/t SKE), *Lu* is lignite use in electricity generation (t SKE)

The conventional gross profit proxy per energy unit (Equation 27) is defined as:

$$Conv\ Profit\ per\ Energy\ Unit\ = \frac{convGR - fuel\ costs}{CEG} =$$

$$\frac{convGR - [(NGp \cdot NGu) + (HCp \cdot HCu) + (Lp \cdot Lu)]}{CEG}$$

Equation 27: Conventional Profit per Energy Unit

Here, *convGR* is conventional generation revenue (million€) as calculated in Conv. Tariff measure, and *CEG* in conventional electricity generation as calculated in Conv. Tariff measure.

2. Ratio of conventional installed capacity to peak load

The second measure is used to study the degree to which conventional electricity generation, and dominant firms can threaten reliable electricity supply by "holding back supply". As the ratio of conventional installed capacity to peak load decreases there remains a smaller "capacity buffer" to uphold supply in case of low variable generation, particularly when coinciding with high demand. Thus, dominant firms' potential threat to reliable electricity supply increases as the ratio decreases.

The measure of threat to reliable supply (Equation 28) is defined as:

$$CIC/PL\ ratio\ = \frac{CIC}{APHL}$$

Equation 28: Conventional installed capacity to peak load ratio

Where *CIC/PL* ratio is conventional installed capacity to peak load ratio, *CIC* is conventional installed capacity (GW), and *APHL* is annual peak hourly load (GW).

For additional related measures see Appendix 5.5.

1. Ratio of Total Electricity Sales to Revenue from Annual Generation

The third measure expresses the ratio of conventional generators revenue from total sales during a certain year (including forward and future contracts) to the sale of conventional power generated in the same year. It is used to study the volume of forwards in electricity sales, and the degree to which these are used in comparison to spot market contracts. I argue that growing uncertainty about securing supply, due to decreasing conventional installed capacity and increasing VER penetration, may push buyers (retailers as well as industrial customers) to sign forward contracts, hedging against perceived future price rises, and enabling conventional generators to appropriate higher revenues.

The total sales to annual generation sales measure (Equation 29) is defined as:

$$TES/AGR\ ratio = \frac{TES}{AGR}$$

Equation 29: Ratio of Total Electricity Sales to Revenue from Annual Generation

Where *TES* is total electricity sales, including forwards (million€), and *AGR* is annual generation revenue, i.e. revenue from the sale of electricity generated during a certain year only (million€).

2. Conventional Concentration

The final measure is an expression of the share of big firms' revenue in total revenue from conventional generation. Due to data constraints, "big firms" are defined as having >250 employees, in accordance with DeStatis business registry's category of largest firms.[194] For further details on the estimation of big firms' revenue see Appendix 5.5. The higher the share of big firms' revenue, the higher the concentration in conventional electricity generation.

The conventional concentration measure (Equation 30) is defined as:

$$BFS = \frac{BFSR}{convGR}$$

Equation 30: Conventional electricity generation concentration

Where *BFS* is big firms share, *BFSR* is total big firm sales revenue (million€), and *convGR* is conventional generation revenue (million€).

3. Additions to the German *Energiewende* case study conceptual tools explanation

Conventional tariff calculation breakdown

To calculate the conventional energy tariff, I start with data on revenue from electricity generation from the DeStatis business registry. However, its revenue category represents total annual recorded revenue, implying that revenue from the sale of forward and future contracts is also included in the data. As I am interested in the revenue from annual electricity generation only, a further 'demand side' approach was necessary to produce total generation market revenue (TGMR).

[194] Significantly, this category consists of an average of 60 firms between 2010-2021, while the number of electricity generators during this period lies between 33,000-70,000. This core of big firms (which I presume to control mainly conventional generation) includes dominant capital firms, which currently control about ⅔ of conventional production (see table 3.). So, it can be considered as a reasonable proxy for dominant firms' revenue trends in the generation segment.

From a "demand side" perspective, total generation market revenue is calculated as:

$$TGMR = anhEPC * nhEC + ahEPC * hEC + ER - IC$$

Equation 31: Total electricity generation market revenue

Here, *anhEPC* is average non-household energy procurement cost (c€/kWh), *nhEC* is non-household energy consumption (TWh), *ahEPC* is average household energy procurement cost (c€/kWh), *hEC* is household electricity consumption (TWh), *ER* is export revenue and *IC* is import costs.[195]

Total EEG market revenue is calculated as by subtracting all EEG subsidy payments from EEG total remuneration as follows:

$$EEGMR = EEGR - EEGmkp - EEGmnp - EEGfb - EEGfint$$

Equation 32: Total EEG market revenue

Here, *EEGR* is EEG total remuneration, *EEGmkp* is EEG market premium payments (million €), *EEGmnp* is EEG management payments (million €), *EEGfb* is EEG flexibility bonus payments (million€), *EEGfint* is EEG FinT payments (million €).[196]

Thus, I reach the following equation for estimating the conventional electricity tariff:

$$Conv\,Tariff = \frac{convGR}{CEG} = \frac{TGMR - EEGMR}{TNG - EEGEG} = \frac{(ahEPC \cdot nhEC + ahEPC \cdot hEC + ER - IC) - (EEGR - EEGmkp - EEGmnp - EEGfb - EEG}{TNG - EEGEG}$$

Equation 33: Conventional electricity tariff - detailed

195 Values adjusted to scale in all actual computations.
196 Values adjusted to scale in all actual computations.

In the absence of data on revenue from annual electricity generation only, revenue from annual generation is calculated as the sum of the product of average non-household energy procurement price component and non-household electricity consumption, the product of average household energy procurement price component and household electricity consumption and the export surplus (the difference between export revenue and import costs). From total generation market revenue, I subtract EEG market revenue, which is the difference between total EEG remuneration and all EEG subsidy payments.[197]

The tariff ratio

The tariff ratio is defined as:

$$Tariff\ Ratio = \frac{Alt\ Tariff}{Conv\ Tariff}$$

Equation 34: Electricity tariff ratio

Where *Alt Tariff* is alternative electricity tariff (€/MWh), and *Conv Tariff* is conventional electricity tariff (€/MWh).

The ratio of dominant firm installed capacity to peak load

The ratio of dominant firm installed capacity to peak load is expressed as:

$$DIC/PL\ ratio = \frac{rweIC + leagIC + enbwIC}{APHL}$$

Equation 35: Ratio of dominant firm installed capacity to peak load

[197] As explained in the explanation of the third measure, though initially an impediment, the data on total recorded revenue from electricity generation eventually turned out to be a conceptual treasure.

Where *DIC/PL* is dominant firm installed capacity to peak load, *rweIC* is RWE installed capacity (GW), *leagIC* is LEAG installed capacity (GW), *enbwIC* is EnBW installed capacity (GW), and *APHL* is annual peak hourly load (GW).

This measures the ratio of the combined installed capacity controlled by the three dominant firms in electricity generation, and the annual peak hourly load.

Estimation of big firm revenue for 2016-2017

The "Destatis_749196_E12_URS_RE_Abschnitt_E_4Steller_BJ06-21" data series contains data on total annual sales (Umsatz) from electricity supply (2006-2021) broken down to four business segments: electricity generation (Elektrizitätserzeugung), electricity transmission (Elektrizitätsübertragung), electricity distribution (Elektrizitätsverteilung), and electricity trading (Elektrizitätshandel). Sales are recorded in total (insgesamt), and by company size. There are 4 categories of company size: 0-9 employees, 10-49 employees, 50-249 employees, over 250 employees (in Germany). There are slight differences in the categories between the years, but the >250 employees category does not change.

Data on generation sales for the year 2016-17 is missing for both 50-249 employees and >250 employees. I estimated these values by subtracting the sum of all remaining categories from total sales and then multiplying the result by the average ratio of the >250 employees category to the 50-249 category.

Appendix 6: MaStR data aggregation methods and analysis measures explanation

This appendix contains a detailed explanation of the MaStR analysis measures, the data variables available on the MaStR registry, as well as the queries I ran on the data to create the six categories, namely: Commission date, Operator type, Capacity class, Energy class, Energy source class, and Is dominant operator.

Table 28: MaStR database variables

Publicly available power plant variables (originally in German)	
MaStR unit number	Last update
Unit name	Date of planned commissioning
Operational status	Name of the plant operator (organisation only)
Energy sources	Plant operator MaStR number
Gross power rating	Full feed or partial feed
Net power rating	MaStR approval number
Commissioning date	Name of the connection network operator
Registration date	MaStR no. of the connection network operator
Federal State	Network operator check
Community key	Voltage level
Number of solar modules	MaStR EEG system number
Main orientation of the solar modules	EEG system key
Wind farm name	Commissioning date of EEG system
Hub height of wind turbine	Installed capacity
Wind turbine rotor diameter	Surcharge number (EEG/KWK tender)
Wind turbine manufacturer	MaStR CHP plant number
Type designation	Commissioning date of the CHP plant
Main fuel of unit	Electric CHP power
Usable storage capacity in kWh	Thermal performance in kW
Power generation technology	

Table 29: MaStR Categorization Queries

Category	***Values***	***Query***
Commission Date	1900-2021	
Operator Type	Person	Name of the plant operator contains “Naturliche Person”
	Firm	Name of the plant operator contains AG, KG, GmbH, mbH, co.[198]
	Cooperative	Name of the plant operator contains eG
	e.K	Name of the plant operator contains e.K
	e.V	Name of the plant operator contains e.V
	GbR	Name of the plant operator contains GbR
	OHG	Name of the plant operator contains OHG
	Public	Name of the plant operator contains
	Other	
Capacity Class	Small < 100 kW	Installed capacity < 100kW
	Large > 100 kW	Installed capacity > 100kW
	Utility > 1 MW	Installed capacity < 1000kW
	Legacy > 500 MW	Installed capacity < 5000kW

[198] All upper/lower case combinations, containing/dropping periods and spaces were included in the search.

Table 29: MaStR Categorization Queries - continued

Energy Class	Alternative	Main fuel of unit is Onshore Wind, Offshore Wind, Solar PV, Geothermal, Biomass or Waste
	Conventional	Main fuel of unit is Hard Coal, Lignite, Natural Gas, Nuclear, Oil. Mineral Oil Products, Hydro
Energy Source Class	Renewable	Main fuel of unit is Onshore Wind, Offshore Wind, Solar PV, Geothermal, Biomass
	Fossil	Main fuel of unit is Hard Coal, Lignite, Natural Gas, Nuclear, Oil
	Other	
Is Dominant Operator	0 1	Name of the plant operator Contains Innogy SE | innogy SE | EnBW Energie Baden-Württemberg AG | Vattenfall Wärme Berlin AG | Uniper Kraftwerke GmbH | RWE Generation SE | Vattenfall Heizkraftwerk Moorburg GmbH | Vattenfall Wasserkraft GmbH | RWE Power AG | Vattenfall Europe Wärme AG | E.ON Kernkraft GmbH | Vattenfall Europe Nuclear Energy GmbH | Vattenfall Hamburg Wärme GmbH | Vattenfall Europe New Energy Ecopower GmbH |

Table 29: MaStR Categorization Queries - continued

		Vattenfall via Vattenfall Europe Nuclear Energy GmbH | EnBW Kernkraft GmbH | Preussen Elektra GmbH | Lausitz Energie Kraftwerke AG | Stadtwerke Düsseldorf AG | Grosskraftwerk Mannheim AG | Bayerische Elektrizitätswerke GmbH | Energie- und Medienversorgung Sandhofer Straße GmbH & Co. KG | Energiedienst AG | Energiedienst Holding AG | Energieversorgung Oberhausen AG | Gemeinschaftskraftwerk Irsching GmbH | Gemeinschaftskraftwerk Kiel GmbH | Gemeinschaftskraftwerk Veltheim GmbH | GHD Bayernwerk Natur GmbH & Co. KG | Kernkraftwerk Obrigheim GmbH | Kraftwerk Schwedt GmbH & Co. KG | Müllheizkraftwerk Rothensee GmbH | Obere Donau Kraftwerke AG | Peissenberger Kraftwerksgesellschaft mbH | Peißenberger Wärmegesellschaft mbH | Schluchseewerk Aktiengesellschaft
Net Capacity	In kW	

MaStR analysis measures additional explanations

Alternative installed capacity

This variable represents the aggregate amount of energy that all renewable generation units connected to the German electricity network are able to produce. I differentiate between *corporate owned alternative installed capacity* and *individually owned/prosumer alternative installed capacity* to trace changes in the ownership structure of renewables in aggregate and as percent change. I defined *corporate owned renewable capacity* as capacity whose operator type was identified as "Firm" and energy source class was identified as "Renewable".

As explained above, the "Firm" operator type was constructed by running a query on the "Name of plant operator" MaStR variable which defined "firm" as any operator name containing the acronym AG, KG, GmbH, mbH, co., or a combination of the above.

The "Person" operator type was constructed by running a query on the "Name of plant operator" MaStR variable which defined "person" as any operator name containing the phrase "Naturliche Person".

The "Renewable" energy source class was constructed by running a query on the "Main fuel of unit" MaStR variable which defined "energy source class" as Onshore Wind, Offshore Wind, Solar PV, Geothermal, Biomass.

Renewable energy sources-based installation by size

I differentiate between *small-scale alternative installed capacity*, *large-scale alternative installed capacity*, and *utility-scale alternative installed capacity* to trace changes in techno-spatial centralization of renewable-sourced power generation in aggregate and as percent change.

Following Ritchie and Roser (2017) I defined plant size class according to the following queries:

Table 30: Plant size class by installed capacity

Capacity class	***Installed Capacity***
Small	Installed capacity < 100kW
Large	Installed capacity > 100kW
Utility	Installed capacity < 1000kW

Renewable energy sources penetration rate

The degree RES and VER integration is often referred to as penetration, denoting their share (%) in a system's energy mix. I calculated it as share of alternative resources in total net installed generation capacity or:

$$RES\ penetration\ = \frac{total\ RES\ installed\ capacity}{total\ installed\ capacity}$$

Equation 36: Renewable energy sources penetration

I studied changes in RES penetration as percent change.

Appendix 7: Basic questions for in-depth interviews

Table 31: In-depth interview questions – conventional electricity generation firms representatives

Question
Tell me about the company? (year of establishment, history, preset outlook and performance)
What is your position, how long have you been holding it?
What does the company wish to achieve regarding energy decarbonization, how does it aim to bring this about?
What is the company's position on different aspects of the Energiewende? (approach to climate change, decentralization, decommission, EEG, levy, renewables, state-led change, subsidies etc)
How has the role of incumbents changed with the Energiewende? How do you propose to fulfil this role?
How has the Energiewende affected the company and its activity, performance, risks, strategies?
How has corporate policy changed with regulatory changes?
How do you see the risks facing the company and the sector? How do you propose to deal with them?
How have changes affected corporate income? How have you responded to these changes?
Have there been mistakes? Lessons learned?
Describe to me the company's strategy regarding renewable energy?
Describe to me the company's strategy regarding decommissions? How have these affected the company and the sector?
How does the company intend to fulfil its role in reliable electricity supply?
What do you consider the most significant investment decisions made during the past decade? (M&A, fixed capital investments?)
Describe to me the company's role in the sector? Regarding reliable supply? How has this affected your sales strategy? How has this affected your investment policy? What is the volume of forward contracts in your sales?

Table 31: In-depth interview questions – conventional electricity generation firms representatives – continued

Above questions regarding regulation with specific focus on recent changes and the introduction of the auction system
What is the firm's fuel mix and how do regulatory considerations affect its development?
What is the company's sale strategy? How has it changed? To what degree do you engage in PPA's and over the counter trading? On what basis are prices set in forward contracts for conventionals?
What are the effects of changes in energy prices for generators on the development of the sector? How have major changes in the ownership structure of the generation segment affected the company?
What do you consider the company's most significant investment decisions over the past decade to be? Which have been more significant mergers and acquisitions or fixed capital investments?
Could you describe the firm's strategy regarding renewable energy? What business and regulatory environment would be required to uphold this strategy? Could you describe the firm's strategy regarding decommissions? How have these affected the company and the sector? How is the company affected by the need to maintain a capacity reserve?
Describe to me the major successes and failures which you recognize in your recent company's history? (How do you understand them, what facilitated/caused them?)
Could you give me some examples of orchestrated actions the energy industry has taken vis a vis the energiewende? Could you estimate changes in the ownership structure in generation? In renewable generation? In conventional generation?
How have political and environmental conditions changed and how does this affect your company? Describe to me in your own words the social context within which you act?
How do you see the future? How do you understand the future of the Energiewende and renewable energies in Germany? What is required in these respects?

Table 32: In-depth interview questions - Transmission system operator representatives

Tell me about the company? (year of establishment, history, sectoral role, responsibility, how have these changed with the Energiewende?)
What is your position, what do you do, how long have you been working at the company?
What is your position on the Energiewende and the way it has been implemented, as a system operator? (decarbonization, renewable penetration, decentralization, decommission, EEG levy, auctions, subsidies etc)
How did transmission operation have to adapt to renewable penetration?
How has the role of incumbents changed with the Energiewende?
Describe to me the capacity reserve of the grid, as well as of different plant types?
What is the average utilization capacity of different plant types?
What is the potential for new capacity connections and how much of it is realized?
How do previous commercial contracts affect new capacity connection rates?
Describe your work vis a vis incumbents (responsibilities, communication, division of labour)
Describe supplier performance? Have there been noticeable changes?
Could you estimate the change in the connection of new prosumer capacity?
Could you estimate the change in the ownership structure of conventionals? Of renewables?
Could you estimate changes in renewable penetration rate?
Describe to me the challenges and developments in grid connectivity, integration, data processing, response-time, Reliability and Stability
Describe to me the effects of the Energiewende on these issues
Are opportunities and potentials fully realized? Why not? What is impeding on realization?
Describe the regulatory framework relevant to your role and changes therein? (how do these affect the TSO's role?)
How do you see the future? How do you understand the future of the Energiewende and renewable energies in Germany? What is required in these respects? (regarding regulation and infrastructure development)

Appendix 8: Internal breadth and energy capture in 20th century UK

Looking into the 20th century, interesting patterns in the relations between changes in the breadth and depth of societal energy capture, and differential accumulation regimes cycles, emerge. Accompanying the early processes of dominant capital consolidation, a shift to internal breadth strategies (i.e., mergers and acquisitions), began to take place as businesses grew in absolute and relative terms.

Figure 49 present a 10-year trailing average[199] of the Buy to Build indicator[200] alongside a 10-year trailing average of annual rate of change in UK useful work, exergy, and energy conversion efficiency,[201] respectively. Figure 50 presents the same data differently, divided into two periods, 1900-1955, and 1955-1999. The Buy to Build indicator represents the degree to which business strategies rely on internal in relation to external breadth. Thus, the figures allow us to explore the relations between changes in business strategies and in the breadth and depth of energy capture in broad strokes.

The series of figures shows the 20th century can be divided roughly into two periods, according to relations of changes in energy capture and business strategies. During the period before the post WWII stabilization of the welfare-warfare state model (~1900-1945), decline in the growth rates of breadth and depth of energy capture was coupled with an increasing reliance on internal breadth strategies in differential accumulation (see Figure 49, light grey areas, and

[199] The data is smoothed using a trailing average, for which each data point represents the average of its value and those of the preceding 9 years.

[200] The Buy to Build indicator is a ratio of the total value of mergers and acquisitions activity to gross fixed capital formation. It "corresponds roughly to the ratio between internal and external breadth" (Nitzan & Bichler, 2009: 338), thus representing the degree to which capitalists engage in mergers and acquisitions in relation to greenfield investment.

[201] Exergy represents the amount of energy available to perform work within a system, useful work is defined as the sum of total work performed within a system, and energy conversion efficiency is the ratio of useful work to energy inputs required for its performance. For further details see Appendix 4.1.

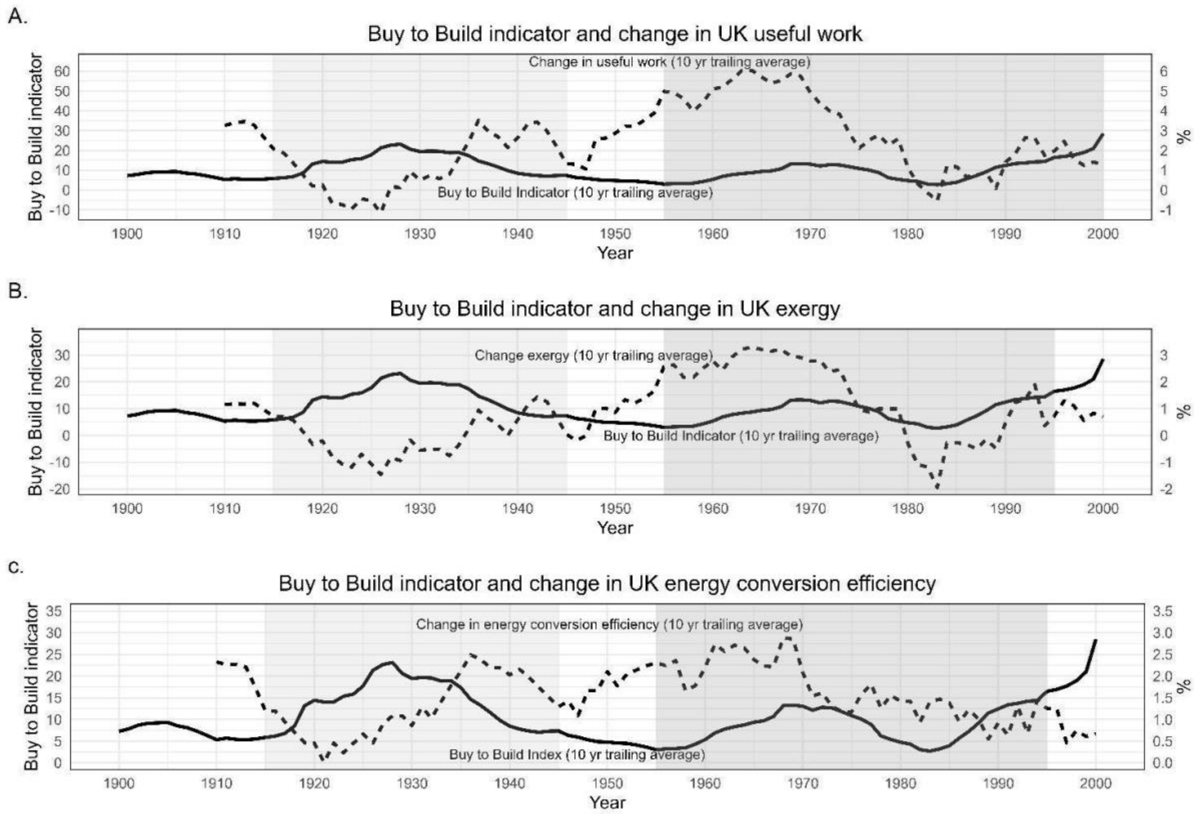
Figure 50, panels A. and C.). This means that as the growth rates of exergy, useful work and conversion efficiency *declined*, business engaged increasingly in mergers and acquisitions, and less so in greenfield investment.

When internal breadth (mergers and acquisitions) capacities were exhausted, a period of external depth ensued (stagflation, i.e., the economic crisis of the 1930's). During the second period (~1945-1999), a rise in the breadth and depth of energy capture was coupled with a rising reliance on internal breadth strategies, corresponding to an increase in controllable productive industrial capacities, and thus occurring at a five-year lag of the buy to build index in relation to change in the energy variables. This means that during the second period, as rates of change in exergy, useful work, and conversion efficiency *increased*, business came to rely heavily on mergers and acquisitions once again. Seeing as businesses were buying up existing industrial capacity, the increase in mergers and acquisitions activity lagged five years behind the rise in change in energy capture.

The shift to an external depth (stagflation) regime occurred alongside a slowing down in the growth rate of the breadth and depth of energy capture, and its reversal (i.e., the crises of the 1970's and 1980's) (see Figure 49, dark grey areas, and Figure 50, panels B and D).

An interesting exception to this pre/post welfare-warfare state division is the period between 1945-1955. Here we can see a rise in useful work and exergy accompanied by a declining Buy to Build indicator (see Figure 49, white areas between the grey). This may indicate that during this period (and this period alone) rising breadth and depth of energy captured was employed more "industriously" to improve the general welfare, as growing energy capture capacities were employed in greenfield investments and increased industrial capacity. Immediately after, in 1955, rising exergy and useful work began to move in tandem with a rising Buy to Build indicator, indicating that rising breadth and depth of energy capture support the growth of hierarchical power structures, and the consolidation of dominant capital through internal breadth activity.

Figure 49: Buy to Build indicator and change in UK useful work, exergy, and conversion efficiency 1900-2000

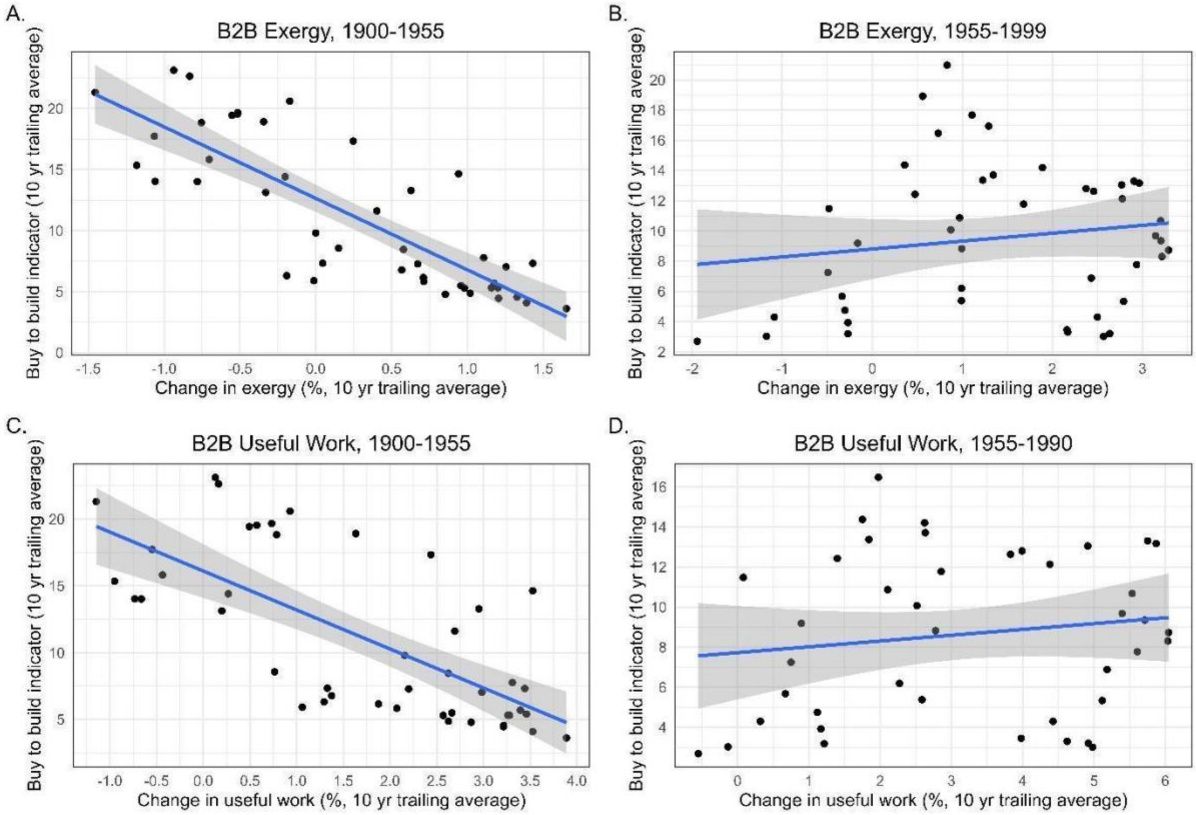


Source: UK Buy to Build indicator: Francis, 2018a: 1, UK Buy to Build dataset. Useful work, Exergy, and Conversion efficiency: Warr, et al., 2010: Table 1.J. Aggregate Time Series (GDP, Capital, Labour, Exergy, Useful Work and Efficiency).

As presented in Figure 50, Panels A and C, the Buy to Build indicator's 10-year trailing average and the 10-year trailing average of the change in exergy and useful work are inversely proportional during the first period of 1900-1955. The results of the linear regression model for this period are significant at the level of $p < 0.01$ for exergy and $p < 0.001$ for useful work. Note that for this period, the results of the linear regression for the unsmoothed series also display a reverse proportionality, significant, at the level of $p < 0.05$.

As can be seen in Figure 50, Panels B and D, the variables are proportional to each other during the second period of 1955-1999. The results of the linear regression are not significant for the whole period. Nevertheless, as can be seen in Figure 51, the results of a linear regression for the years 1955-1990 in which the buy to build indicator is lagged by five years[202] display a proportional relation and are significant at the level of $p < 0.001$.

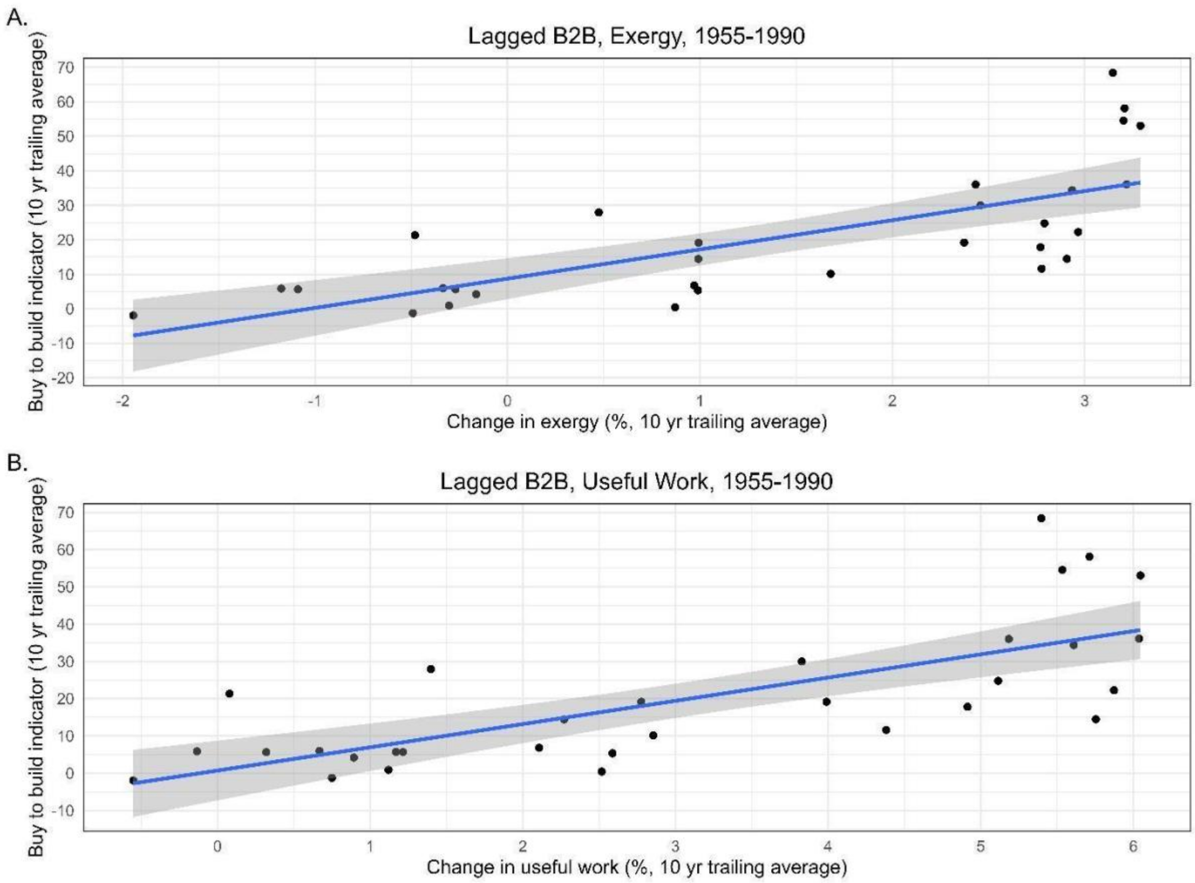
Figure 50: Buy to Build indicator and change in UK exergy and useful work, 1900-1999



Note: Blue line represents linear regression model, grey ribbon represents confidence intervals.
Source: see Figure 49.

[202] This means that while data on change in exergy and useful work is taken for the years 1955-1985, data for the buy to build indicator is taken for the years 1960-1990.

Figure 51: Lagged Buy to Build indicator and change in UK exergy and useful work, 1955-1990



Note: Blue line represents linear regression model, grey ribbon represents confidence intervals.

Source: see Figure 49.

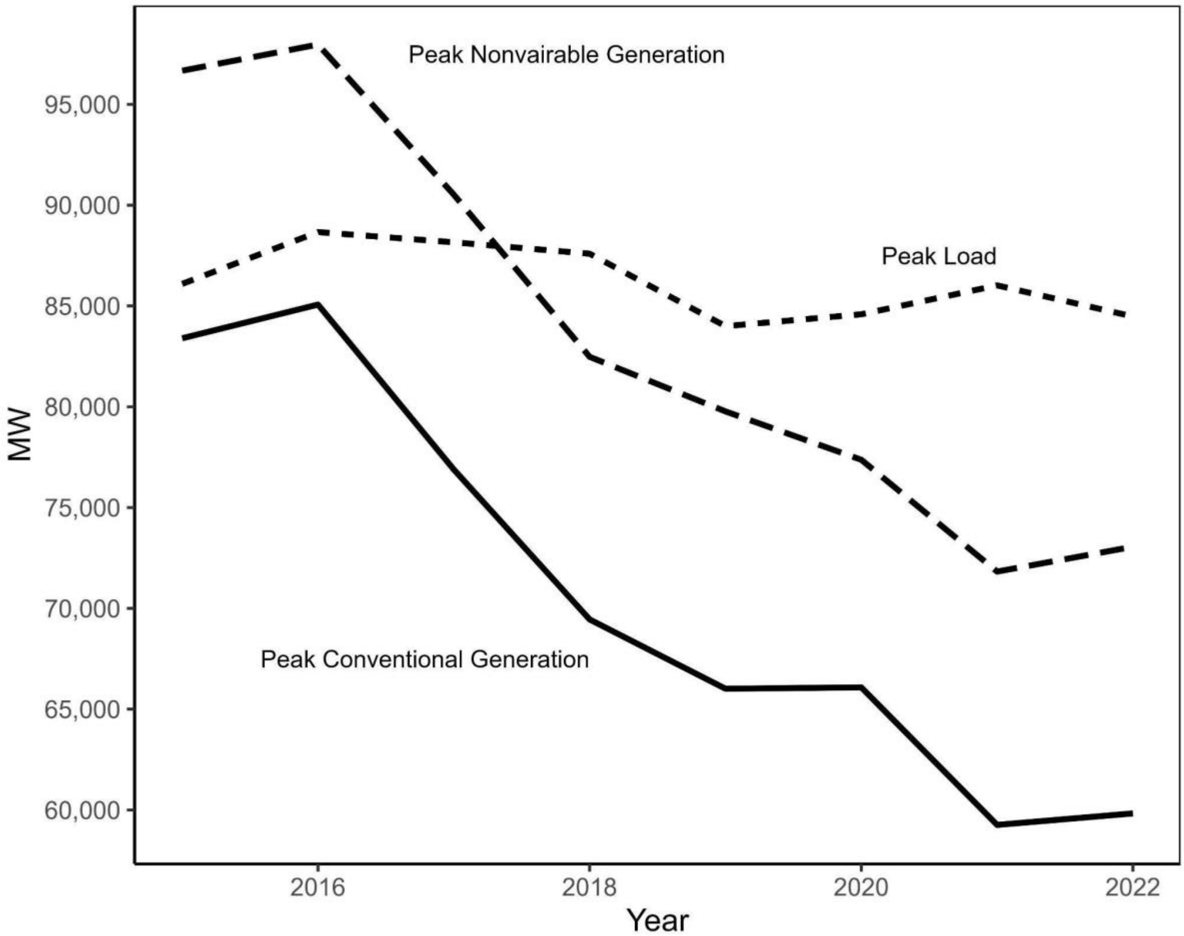
The analysis of 20th century dynamics is preliminary, drawing only broad research trajectories which beg a more detailed and thorough analysis which is beyond the scope of this dissertation.

Appendix 9: Peak load and peak non-variable generation

Figure 52 shows the peak annual 15-minute load and peak conventional and non-variable generation.

Note that the levels of conventional and non-variable peak 15-minute generation (i.e. the 15 minutes during a year in which CEG load was the highest) remain close to those of annual peak load. This implies that while traditional generators' share in total net generation has declined, their installed capacity is still critical to ensure reliable supply.

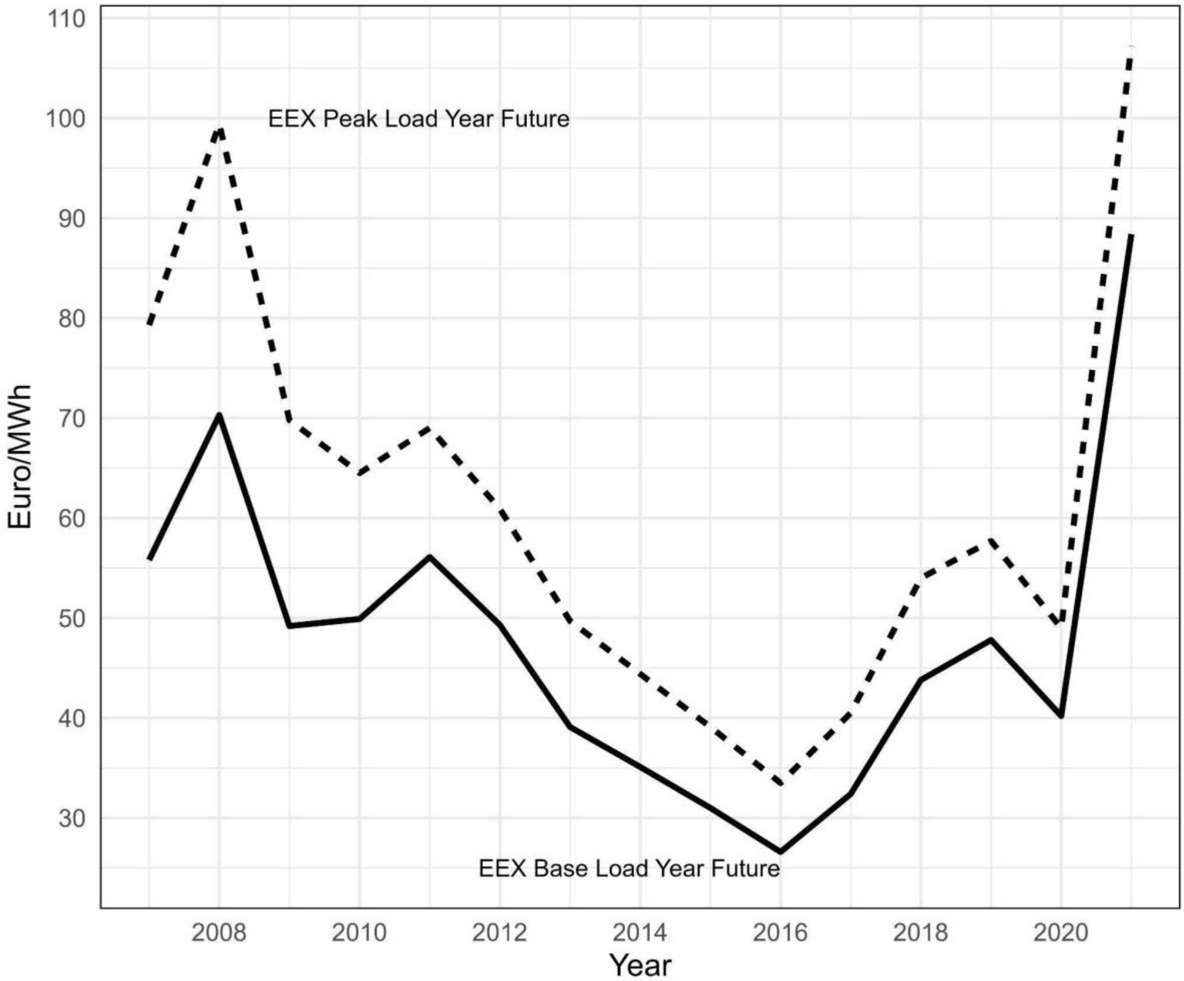
Figure 52: Peak Load and Conventional Electricity Generation, Germany, 2015-2022



Note: Peak conventional generation refers to fossil-fuel and nuclear generation.
Source: Data on 15-minute net electricity generation and load (2015-2022) was retrieved and compiled from Fraunhofer ISE: https://www.energy-charts.info/charts/power/chart.htm?l=de&c=DE&interval=year&source=total

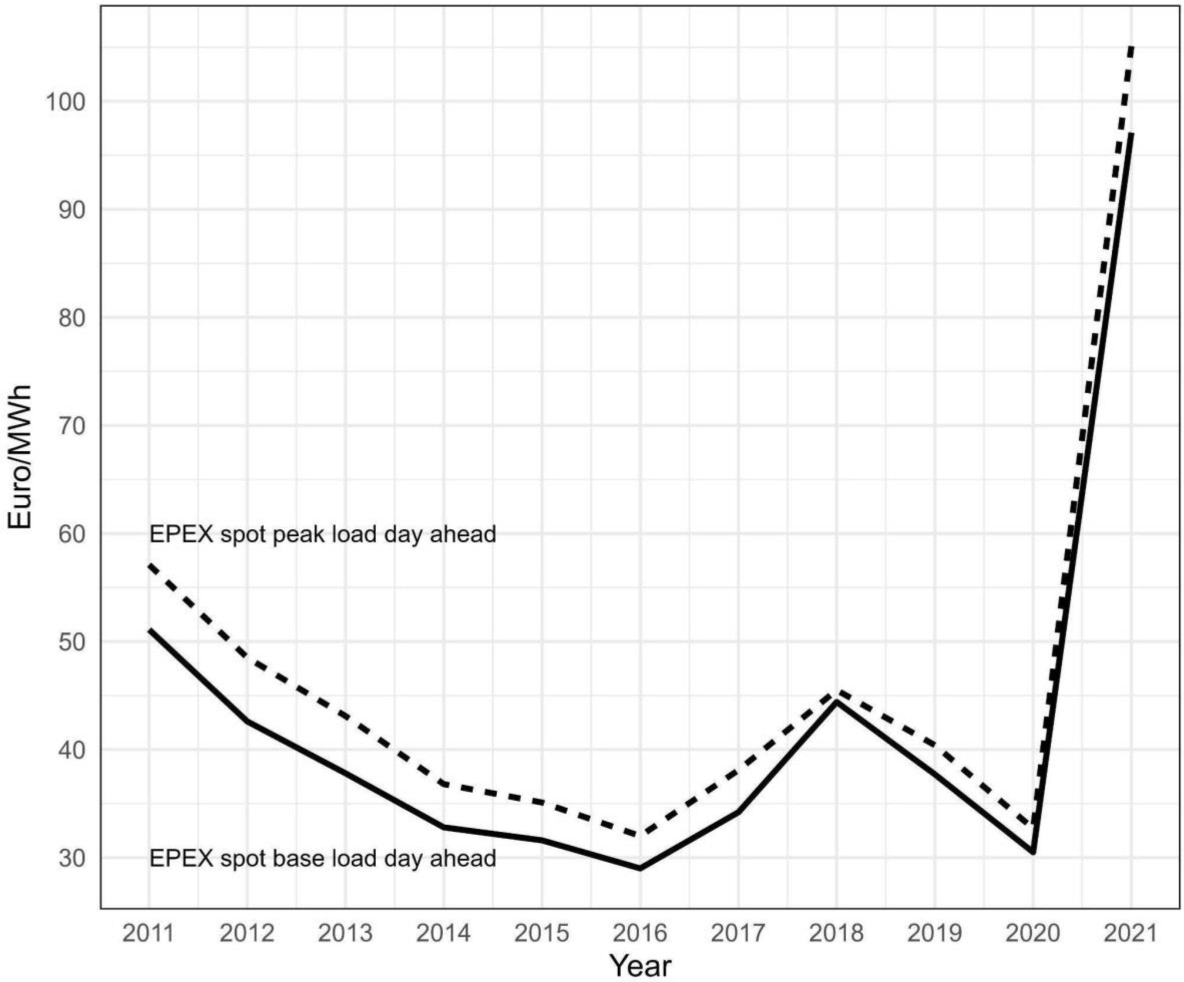
Appendix 10: EEX future and EPEX SPOT day-ahead market price development

Figure 53: EEX future market price development, 2007-2021



Sources: data on average EEX future prices were compiled from BnetzA monitoring reports 2012-2022.

Figure 54: EPEX SPOT day-ahead market price development, 2007-2021



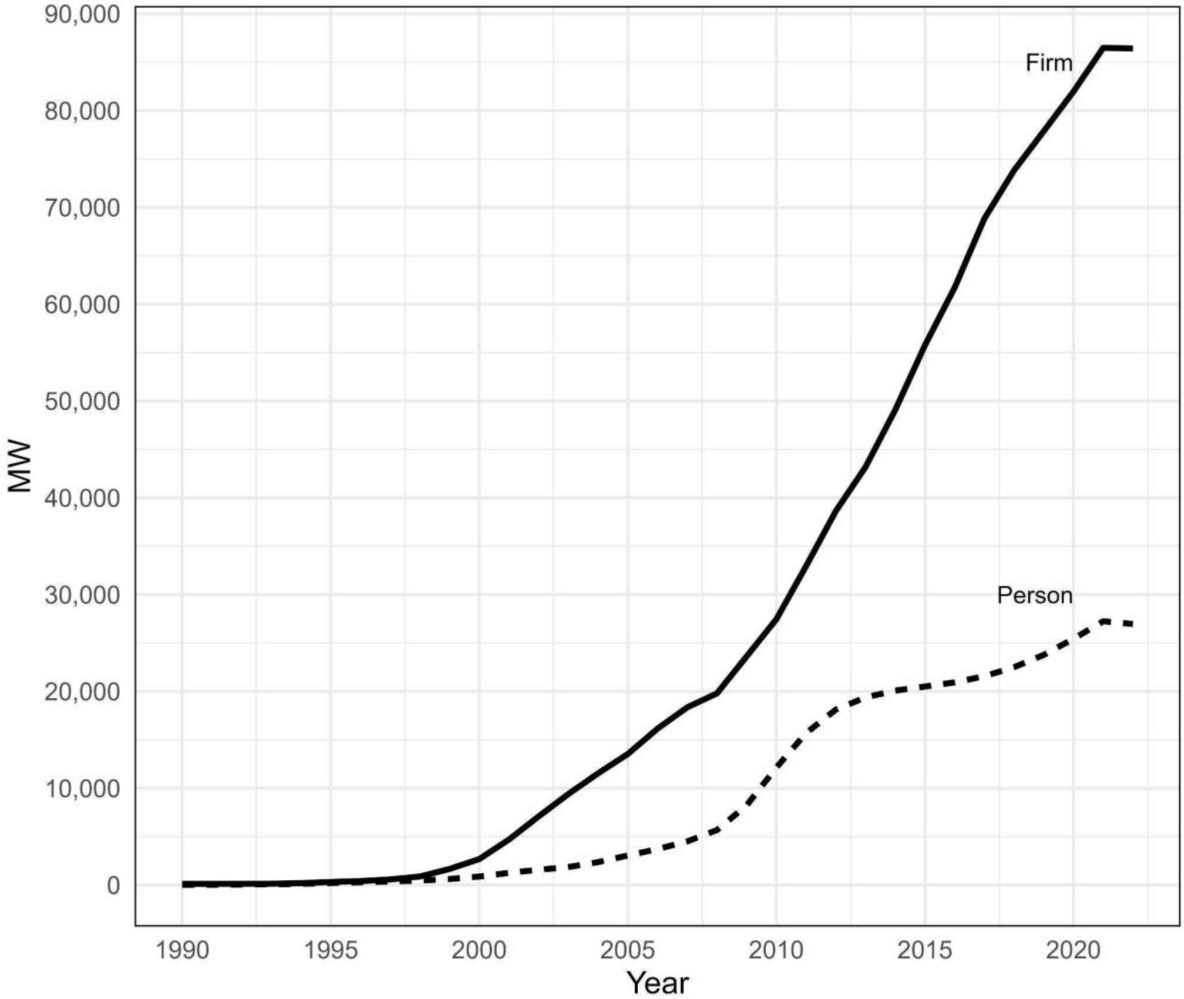
Sources: data on average EEX future prices were compiled from BnetzA monitoring reports 2012-2022.

Note that while average EEX Year Futures began to rise in 2017 (as do conventional total electricity sales relative to yearly conventional revenue), average EPEX SPOT Day-Ahead prices rose only in 2021.

Appendix 11: Alternative electricity generation development trends

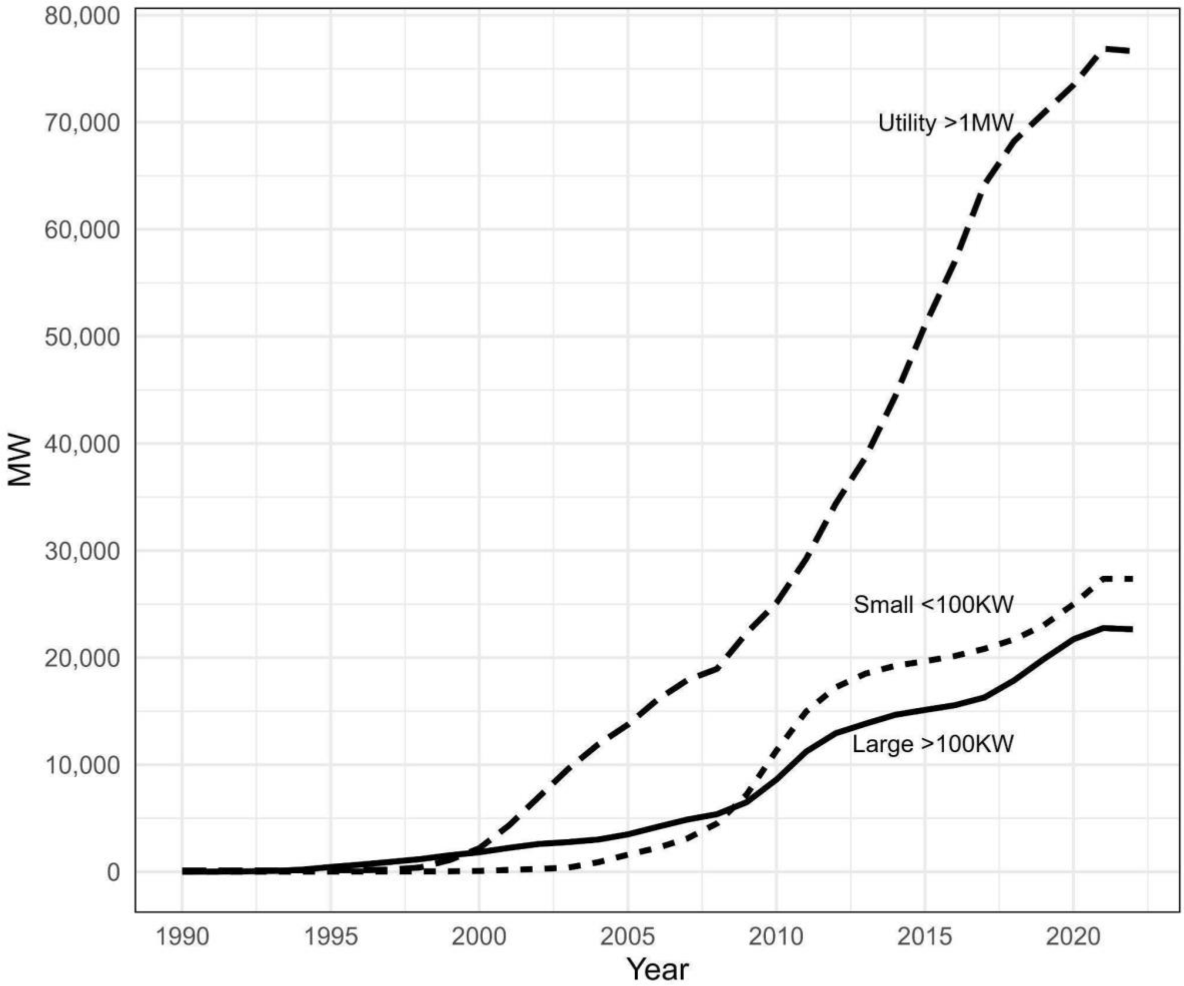
Figure 55 and Figure 56 show a coinciding rise in renewable ownership concentration and spatio-physical centralization. While renewable prosumer installed capacity began to stagnate around 2012, renewable firm-owned installed capacity rose steadily and steeply, almost tripling in the decade between 2011-2021 (from approximately 30 GW to almost 90 GW). The same trend is displayed in the development of renewable installed capacity by plant size.

Figure 55: Alternative Installed Capacity by operator type, Germany, 1990-2021



Note: Data was aggregated according to operator type, plant size, energy source, commission year, and decommission year. For further details see appendix 7. Source: MaStR Stromerzeugungseinheiten register https://www.marktstammdatenregister.de/MaStR/Einheit/Einheiten/OeffentlicheEinheitenuebersicht Accessed: 30.9.2023

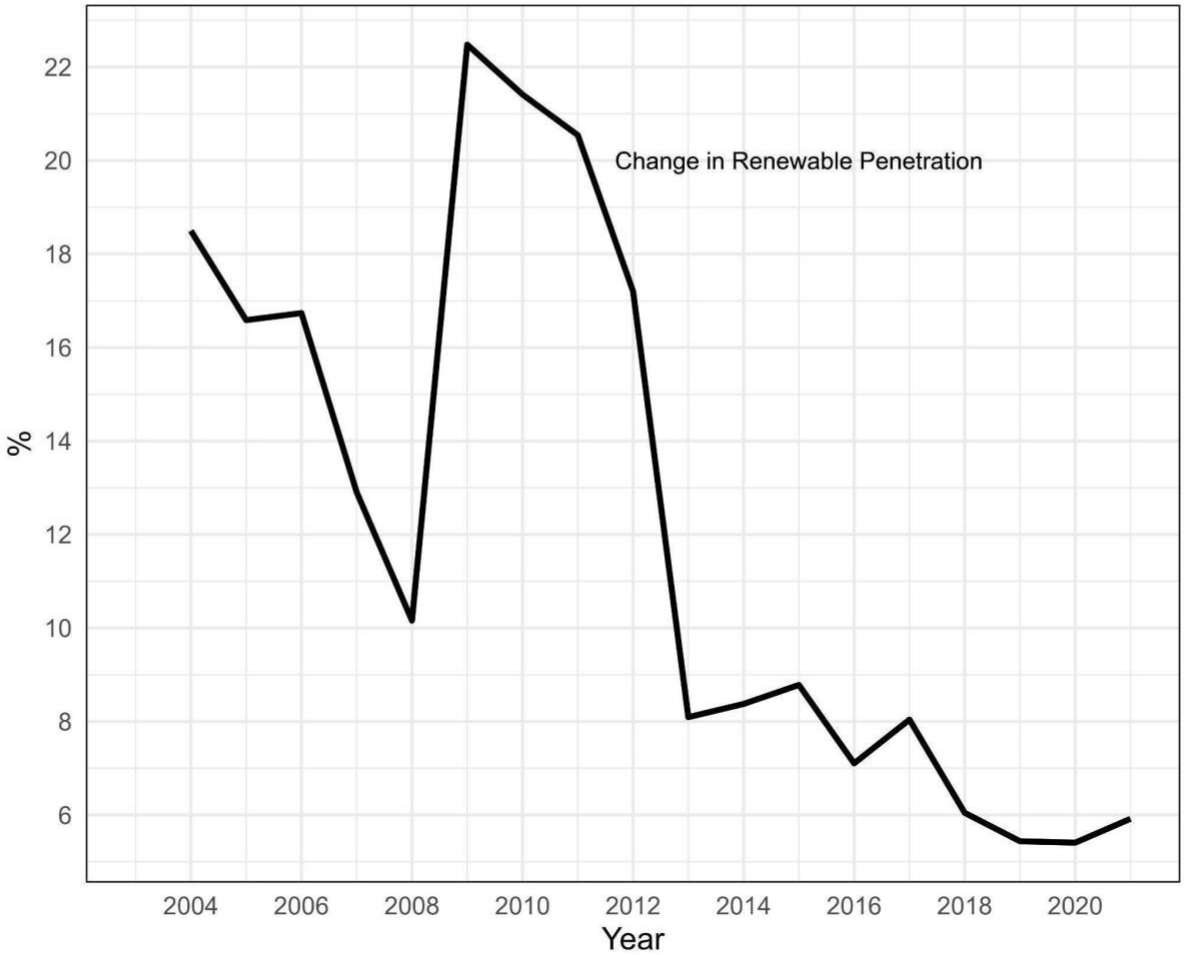
Figure 56: Alternative Installed Capacity by plant size, Germany, 1990-2021



Sources: see Figure 55.

As shown in Figure 57, these results coincide with declining AEG penetration rates. In 2010, the percent change in AEG installed capacity began to decline, from 22% in 2009 to 6 % in 2021, the main drop occurring between 2010-13 (from 21% to 8%).

Figure 57: Change in Renewable Energy Sources Penetration, Germany, 2004-2021



Note: Change in share of alternative resources in total net installed generation capacityTNNGC was calculated by subtracting the share of EEG eligible total net installed generation capacityTNNGC in total net installed generation capacityTNNGC in year n from the same share in year n-1, dividing the result by the share of EEG eligible total net installed generation capacityTNNGC year n-1, and multiplying by 100. Source: Total net installed generation capacityTNNGC and Share of EEG eligible total net installed generation capacityTNNGC in total net installed generation capacityTNNGC were compiled from BnetzA Monitoring Reports 2013-2022.

These figures are the result of an analysis of the Marktstammdatenregister (MaStR). MaStR is BnetzA's open access, comprehensive, online electricity and gas market registry. It includes a mandatory register of electricity generation units (power plants). The power plant register contains over 4 million entries, with a commission year span ranging from 1900-2021 (updating). I downloaded all the entries and uploaded them to SNOWFLAKE database. Using SQL queries, I aggregated the data annually, grouped by the categories shown in Table 11.

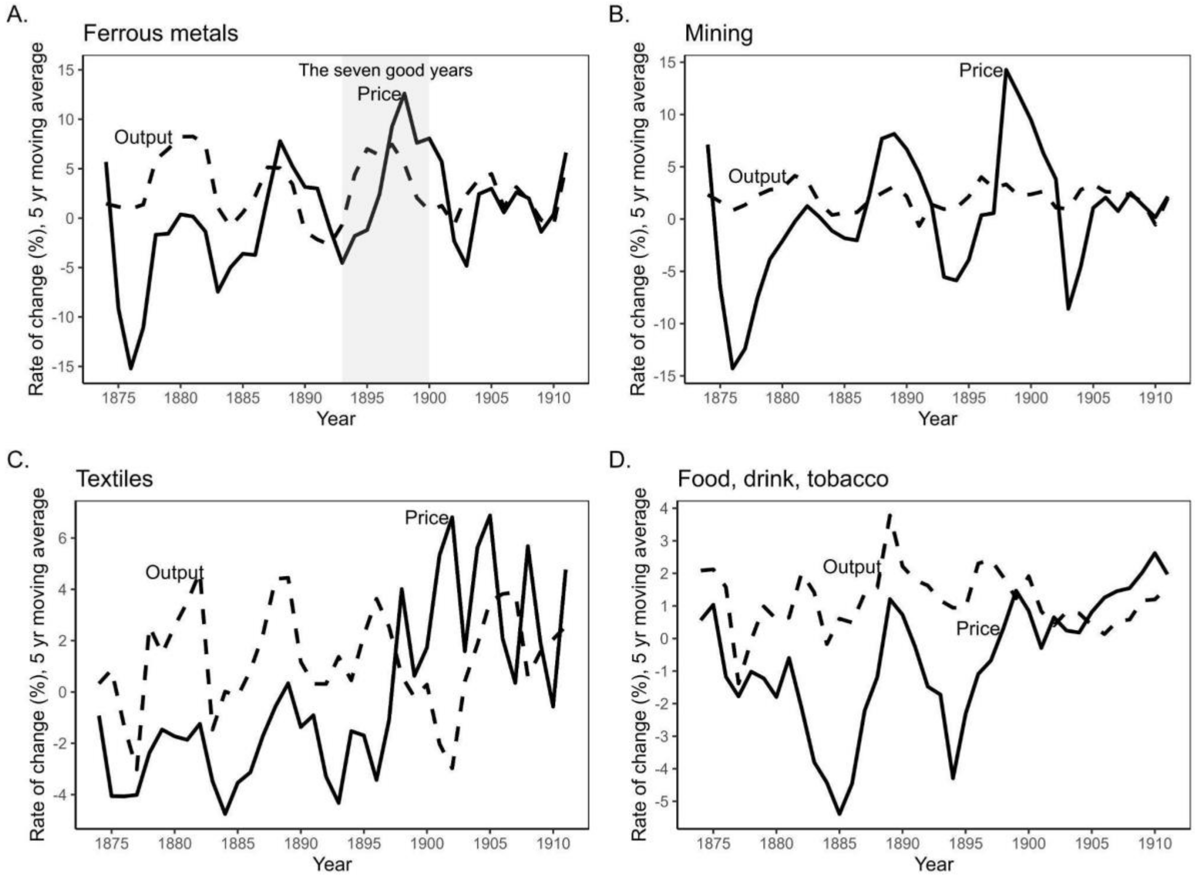
After aggregating the data, I exported the aggregated data as a CSV file and imported it into R, in which all further analysis was performed.

A cumulative installed capacity sum was then computed for each year by category. This was done by summing all commissioned installed capacity up to a given year and then subtracting the sum of decommissioned capacity. All data sets and R scripts used for this study are available on the project's Open Science Network account.

Appendix 12: Output and price index trends, Britain, 1875-1913, selected industries

Figure 58 compares the development of rates of change in output and prices (five years moving averages) in ferrous metals manufacturing (Panel A), mining (Panel B), textiles manufacturing (Panel C), and food, drink and tobacco manufacturing (Panel D). As discussed in the main body of the text, only in ferrous metals manufacturing do average rates of change in output anticipate average rates of change in prices between 1885-1905. This is a possible indication of a shift from price-taking behaviour to price-making practices within this industry.

Figure 58: Change in output and price indices by industry (%, 5 year moving average), Britain, 1875-1910



Sources: Price indices for pig iron, coal, textiles, and food, drink and tobacco: Great Britain Board of Trade (department of labour statistics), 1915: 88-89, Index Numbers for Wholesale Prices: All Groups and Index Numbers for Wholesale Prices: coal and metals. Output indices for ferrous metals, mining and quarrying, textiles, and food, drink and tobacco: Feinstein, 1972: T111, T114: Table 51: Index of Industrial Production by Main Orders, 1855-1965, and Table 52: Index of Industrial Production, Selected Manufacturing Industries, 1855-1948.

Appendix 13: List of Interviewees

CEG Firms Representatives

Adrian - A senior manager at one of the dominant German CEG firms, employed at the firm for over 20 years. Date: 4.7.2024. Length: 45 minutes. Location: Zoom.

Leo - A senior manager at one of the dominant German CEG firms, employed at the firm for approximately 20 years. Date: 29.5.2024. Length: 1 hour and 50 minutes. Location: Zoom.

Gunter - A senior manager and technical team head at a big German CEG firm, employed at the company for approximately 10 years. Date: 18.7.2024. Length: 50 minutes. Location: Zoom.

Axel - A senior manager and advisor at a big German CEG firm, employed at the company for over 20 years. Date: 31.7.2024. Length: 1 hour and 30 minutes. Location: Zoom.

BDEW Representatives

Marius - A senior energy policy advisor, working with the BDEW as well as the German and other European governments. He left the BDEW a few weeks before our interview, after working there for several years. Date: 21.3.2024. Length: 55 minutes. Location: Zoom.

Stephan - An employee of the BDEW's politics and strategy team. Date: 15.4.2024. Length: 55 minutes. Location: Zoom.

Felix - A senior manager at the BDEW economics department, employed at the association for over 20 years. Date: 7.3.2024. Length: 1 hour and 25 minutes. Location: Zoom.

TSO Representatives

Clara - An energy policy team leader at one of the German TSOs, employed at the firm for several years. Date: 3.7.2024. Length: 55 minutes. Location: Zoom.

Inga - An employee at the same TSO as Clara. Part of the national strategy team. Date: 3.7.2024. Length: 55 minutes. Location: Zoom.

Ulf - A press officer at one of the German TSOs. He referred several of my questions to his “colleagues at main control”, which answered them in written form. Date: 31.7.2024. Length: 30 minutes. Location: Zoom.

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שינויים בשליטה: הדינמיקה של מעברי אנרגיה וכוח קפיטליסטי

חיבור על מחקר

לשם מילוי חלקי של הדרישות לקבלת התואר דוקטור לפילוסופיה

טיאה רנטה לוי

הוגש לסנט הטכניון - מכון טכנולוגי לישראל

אלול תשפ"ה, חיפה, אוגוסט 2025

המחקר נעשה בפקולטה לארכיטקטורה ובינוי ערים בהנחיית ד"ר אמיל ישראל.

מחברת חיבור זה מצהירה כי המחקר, כולל איסוף הנתונים, עיבודם והצגתם, התייחסות והשוואה למחקרים קודמים וכו', נעשה כולו בצורה ישרה, כמצופה ממחקר מדעי המבוצע לפי אמות המידה האתיות של העולם האקדמי. כמו כן, הדיווח על המחקר ותוצאותיו בחיבור זה נעשה בצורה ישרה ומלאה, לפי אותן אמות מידה.

אני מודה לטכניון על התמיכה הכספית הנדיבה בהשתלמותי.

רשימת פרסומים:

Levi, T., E. Israel, and M. Grubman. (2024). "Power (Re)distribution: How Dominant Capital Regained Control of the Energiewende". *Zeitschrift für Politikwissenschaft*, 34: 295–327.[203]

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[203] תרומת המחברת: המשגה ופיתוח רעיוני, מחקר, מתודולוגיה, מקורות, פיקח מכליל, ויזואליזציה, כתיבה - טיוטת מקור, כתיבה - עריכה ותיקונים. המאמר נכתב על בסיס פרק 3.

[204] תרומת המחברת: המשגה ופיתוח רעיוני, מחקר, מתודולוגיה, מקורות, איסוף נתונים, ניתוח, קידוד, פיקוח מכליל, ויזואליזציה, כתיבה - טיוטת מקור, כתיבה - עריכה ותיקונים. המאמר נכתב על בסיס פרק 5.

תקציר

חקר מעברי אנרגיה חיוני להתמודדות עם אתגרי וסיכוני השינוי האקלימי. עם זאת, המחקר העכשווי חסר גישה מתודית להבנת הקשרים שבין כוח קפיטליסטי, משטרי אנרגיה ודינמיקה מעברית. מחקר זה מציע ניתוח שיטתי של האופן שבו כוח עסקי מעצב ושולט בשינויים סוציו-טכניים תחת תנאים משתנים של המרת אנרגיה ברמת החברה, והצבר הון.

הפרספקטיבה האנליטית החדשנית שפותחה עבור המחקר מבדילה בין ארבעה טיפוסים אידיאליים של מסלולים חברתיים-טכניים (שינוי מבני, קיפאון, חדשנות, וטרנספורמציה) ומקשרת אותם לשינויים ברוחב ובעומק המרת האנרגיה ברמת החברה (אקסרגיה ויעילות המרת אנרגיה, בהתאמה), ולאסטרטגיות הצבר הון דומיננטיות.

הדיסרטציה מבוססת על גישת מחקר משולב: את המחקר הכמותי של יחסי הכוח החברתיים כפי שאלה מיוצגים במחירים דיפרנציאליים משלים ניתוח תוכן איכותני של סדרת ראיונות עומק.

המחקר המשולב בוחן שני מקרי בוחן: התהליך ההיסטורי של הבשלת המעבר לדלקי מאובנים וקפיטליזם תעשייתי בבריטניה של סוף המאה ה-19 ותחילת המאה ה-20; והאנרגיוונדה הגרמני - תהליך מעבר האנרגיה העכשווי המתחולל בגרמניה, המשלב דה-קרבוניזציה של מערכת החשמל הגרמנית עם ארגון מחדש של מבנה הבעלות במשק החשמל. כדי להעמיק את הבנתינו של תהליכי שינוי חברתי-טכני תחת משטר ההון הגלובלי, המחקר בוחן את תהליך האנרגיוונדה המתהווה אל מול תהליך המעבר לדלקי מאובנים שהושלם, בהקשר של תנאי המרת אנרגיה ברמת החברה והצבר ההון הדיפרנציאלי ההיסטוריים הייחודיים להם.

הניתוח הכמותי מבוסס על כלים קונספטואליים חדשים ויעודיים שפותחו עבור מחקר זה. כלים אלה משלבים את הניתוח הדיפרנציאלי של נתונים פיזיקליים, המשמשים לחקר השינוי התעשייתי, עם נתוני רישומים פיננסיים וחשבונאיים, המשמשים לחקר התהליכים העסקיים. מקרה הבוחן הגרמני כולל גם ניתוח של ראיונות עומק עם נציגים עסקיים ממשק החשמל הגרמני.

התוצאות מצביעות על כך שלא צמיחה כמותית בהיקף המרת האנרגיה ברמת החברה, כי אם היכולת לשלוט בתהליך החברתי-טכני עצמו היא החיונית לשימור ושעתוק הכוח הקפיטליסטי. כפי שמוצג בניתוח של שני מקרי הבוחן, שיש להודות שהם שונים מאוד, רק כאשר קבוצות עסקיות דומיננטיות סיגלו לעצמן מנגנון שבאמצעותו הן יכלו לעצב ולשלוט בתהליכי מעבר ושינוי אנרגטיים, ניתן היה למנף תהליכים אלה בתהליך הצבר ההון הדיפרנציאלי.

ניתוח מקרה הבוחן הבריטי עוקב אחר תקופה אותה אני מכנה "שבע השנים הטובות" של ההצבר הדיפרנציאלי של עתירות האנרגיה (1894–1900). במהלך תקופה זו, יד ביד עם התמתנות שיעורי השינוי של תהליך המעבר לדלקי מאובנים, חברות בתעשיות עתירות אנרגיה (ביניהן ייצור מתכות ברזליות וסחורות הנדסיות) החלו להרחיב את מנעד המנגנונים העסקיים שלהן, ולהוסיף על מנגנוני השליטה בתפוקה גם מנגנוני עיצוב־מחיר מוקדמים.

ניתוח מקרה הבוחן של האנרגיוונדה הגרמני מראה כיצד חברות הפקת חשמל דומיננטיות השיבו לעצמן את השליטה המשקית על ידי ריכוז תחת ידיהן של הספק החשמל הקונבנציונלי המצטמצם, ההכרחי להבטחת אמינות אספקת החשמל בתנאים של חדירה מואצת של משאבי אנרגיה מתחדשת. לפיכך, איום מובלע על אמינות אספקת החשמל העתידית העניק לחברות הפקת חשמל קונבנציונלית גרמניות את המנוף הדרוש להעלאת מחירים ולהגדלת רווחים דיפרנציאליים. תהליך זה מלווה בריכוזיות הולכת וגדלה בהתפתחות הפקת החשמל ממקורות מתחדשים בגרמניה, הן מבחינה מרחבית והן במבנה הבעלות, כמו גם בירידה בשיעורי החדירה של משאבי אנרגיה מתחדשים ברשת החשמל הגרמני.

המחקר מציע גישה חדשה ושיטתית לחקר מעברי אנרגיה וכוח קפיטליסטי, המתבססת על בחינה אמפירית של תופעות טכנו-פיזיקליות וכאלה הקשורות ביחסי הכוח החברתיים במסגרת אנליטית אחת. הוא טומן בחובו תובנות חדשות בנוגע ליחסים בין אסטרטגיות עסקיות דומיננטיות לבין המאפיינים הטכנו־פיזיים, ההיקף והקצב של תהליכי המעבר האנרגטי תחת משטר ההון הגלובלי.