SteuerBoard Energie
Governance Mechanisms in a Future Polycentric Energy System

WORKING PAPER

Dr. Lars Holstenkamp, Jan Wiesenthal, Najamul Saqib Memon

FINANCING THE POLYCENTRIC ENERGY TRANSITION

Definitions, literature review and research gaps

September 2022

PROJECTPARTNER

LEUPHANA UNIVERSITY LÜNEBURG
i|ö|w INSTITUTE FOR ECOLOGICAL ECONOMY RESEARCH
ECOLOG INSTITUT FÜR SOZIAL - ÖKOLOGISCHE FORSCHUNG UND BILDUNG gGmbH

FUNDING

SPONSORED BY THE Federal Ministry of Education and Research
FONA Social-Ecological Research

Imprint

Authors:
Holstenkamp, Dr. Lars (Leuphana); Wiesenthal, Jan (Institute for Ecological Economy Research); Najamul Saqib Memon (Leuphana)

Project Lead:
Institute for Ecological
Economy Research (IÖW)
Potsdamer Str. 105, D-10785 Berlin
www.ioew.de/en/

Leuphana University of Lüneburg
Institute of Sustainability Governance
Universitätsallee 1, D-21335 Lüneburg
www.leuphana.de/en/institutes/insugo.html

Dr. Swantje Gährs
Phone: + 49 (30) 884 594 59
Fax: + 49 (30) 882 54 39
E-mail: swantje.gaehrs@ioew.de

Dr. Lars Holstenkamp
Phone: + 49 (4131) 677 1931
Fax: + 49 (4131) 677 2167
E-mail: holstenkamp@leuphana.de

Cooperation Partner:
ECOLOG – Institute for Social-Ecological Research and Education
Lüneburg Office
Wichernstraße 34, Entrance B, D-21335 Lüneburg
www.ecolog-institut.de

This article was written as part of the research project "SteuerBoard Energie – Governance Mechanisms in a Future Polycentric Energy System". The junior research group is funded by the German Federal Ministry of Education and Research (BMBF) through the funding program "Junior Research Groups in Social-Ecological Research" over a period of five years (2020-2025) and enables the scientific qualification of six members of the junior research group via habilitations and doctorates during this period.

For more information on the project: www.steuerboard-energie.org/english/

Summary

The transformation of the energy system will require massive investments in the coming years. The total global investment requirement from 2018-2050 is estimated at 110 trillion US dollars. The magnitude of the investment needs makes it clear: investments are needed by all actors. An increasingly important role is played by citizens. They can invest individually and become prosumers (self-consumers of self-generated electricity) or they can organize themselves in bottom-up models such as Energy Communities, Community Energy or Local Energy Initiatives and jointly finance the investment costs.

But how is financing actually defined? What are the financing instruments? And what are the connections between financing (-instruments) and the energy transition? And what role do bottom-up models play in the energy transition? The aim of this paper is to trace and illustrate the links between financing, energy and the current role of bottom-up models in financing of the energy transition.

Financing can be understood in two different ways. In an energy economic sense, financing means the refinancing of capital employed. This includes energy sector regulations such as energy market design, environmental policies or private contracts. In a managerial sense, financing means the procurement of funds. A distinction can be made here between private and public financing. Not least because of the great importance of the regulatory framework, both aspects - energy policy instruments and financing in the managerial sense - are interrelated: The type and scope of the design of the financial requirement (e.g., the implemented support programs) directly influence the coverage of the financial requirements in the managerial sense. In the context of this study, we provide a brief overview of the various financing instruments. The financing instruments have already been intensively researched. For bottom-up models it emerges that risk-minimizing, transparent instruments such as FITs are advantageous. However, the question arises as to what overall effects on the system the various financing instruments have.

Based on a literature review on energy and financing, four perspectives were identified that have been discussed in past research. These include: micro-level perspectives, policy perspectives ("sustainable finance discourse"), system-level perspectives and literature studying the effects of developments in the energy sector on financial markets ("energy-to-finance"). Each of these perspectives contains elements of all three approaches to the topic of financing (managerial, energy economic, regulatory).

Looking at the bottom-up models, it is clear that considerable changes have taken place in recent years. Both technological progress, which has facilitated decentralized energy generation, and regulatory interventions, such as the Clean Energy Package, have strengthened bottom-up models in recent years. While research on bottom-up models has been conducted in the past in several countries with well established bottom-up models, research needs to be extended to other countries in order to generate transferable results. It is also clear that bottom-up models bring new challenges. One example is a tradeoff between investor risk management and the ability to finance bottom-up models. This also needs to be addressed in further research.

About the junior research group

For the energy transition in Germany to succeed, the energy system must be redesigned: On the one hand, many decentralized actors must be integrated, both technically and organizationally. On the other hand, the newly emerging polycentric energy system must be designed in a sustainable way – in other words, higher-level rules should focus on environmentally, economically and socially just implementation. How do current framework conditions and institutions have to change for this? The junior research group "SteuerBoard Energie", funded by the Federal Ministry of Education and Research (BMBF) within the funding program "Junior Research Groups in Social-Ecological Research", is investigating this question in six qualification theses. Based on the concept on polycentric governance, the researchers are investigating two particularly relevant influences in the transformation as key topics: digitalization and financing. In the area of digitalization, the question is which sustainability potentials digitalization contributes to the energy sector and, in particular, to what extent these sustainability potentials support or enable polycentric approaches. With regard to financing of the energy transition, the research team is examining institutions and actors, legal framework conditions and, in particular, looking at possible financing solutions for the expansion of decentralized renewable energies.

Table of contents

1 Introduction 8

2 Relationship between finance and energy – a literature review 9

2.1 Overview of perspectives on energy and financing..9

2.2 Micro-level perspectives 11

2.3 Policy perspectives: sustainable finance debate...12

2.4 System-level perspectives...13

2.5 Energy-to-finance 15

3 Overview of financing instruments...15

3.1 Managerial financing instruments...15

3.1.1 Public support schemes 16

3.1.2 Financing from private actors 17

3.2 Energy-related financing instruments..17

3.2.1 Environmental policies 17

3.2.2 Energy market design 18

3.2.3 Contracts 20

3.3 Importance of financing instruments for bottom-up models 22

4 Legal framework of energy and financial sectors 23

4.1 Regulating the energy sector – changes & challenges 23

4.2 Bottom-up models & regulation 24

4.3 Financial sector regulation and its impact on the energy sector 25

5 Bottom-up models: Links between actors and their behavior, instruments, legal framework and existing research gap..26

Bibliography 28

List of figures

Figure 1: Financing Terms in the Context of the Energy Transition 8

List of tables

Table 1: Strands of the literature on the relation between energy and financing 10

Table 2: Advantages of ETS and Carbon Tax 18

Table 3: Energy Industry Financing and Funding Instruments 20

List of abbreviations

AIFM	Alternate Investment Fund Manager
CEC	citizen energy community
CfD	contract for difference
EOM	energy-only market
ETS	emission trading system
EU	European Union
FIP	feed-in premium
FIT	feed-in tariff
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
KAGB	Kapitalanlagegesetzbuch
MLP	Multi-Level Perspective
PPA	power purchase agreement
PPP	public-private partnership
R&D	research and development
RE	renewable energy
RECs	renewable energy communities
RES	renewable energy sources
SES	Socio-Ecological Systems [framework]
SME	small and medium-sized enterprise
TIS	Technology Innovation System
UNEP	United Nations Environment Programme
WACC	weighted average costs of capital

1 Introduction

With the Paris Climate Agreement and subsequent global initiatives, countries around the globe have developed financial strategies to meet these goals. Financing enables the necessary transition of the energy system and is decisive for an increased transition speed (BDEW 2019; Polzin et al. 2017; WBGU 2012). The financial sector can have both a retarding and an accelerating effect on the energy transition – the former e.g. through crises (financial crisis of 2007-2008, COVID-19), risk management regulations (Basel IV) (Gaumert 2019) or changes in investment rules (e.g. German Capital Investment Code) (Holstenkamp 2014); the latter e.g. through sustainable finance regulations (RNE 2019; Wierling et al. 2018) or co-evolutionary processes (Hall et al. 2018; Hall et al. 2016).

In the context of the transition of the energy system, the term “financing” covers two different aspects (Güsewell et al. 2021):

– In the energy economic sense, "financing" usually refers to the refinancing of investments in renewable energy plants, electricity, gas and heat grids or plants for heat generation. In this context, state intervention is also referred to as "support scheme". In financial terms, this concerns the question of how to structure financial requirements. Revenues mainly formed by energy market design, environmental policies and/or private and public contracts are used to “refinance” investments into powerplants.

– In a managerial sense, financing refers to the coverage of financial needs. Here we distinguish public from private instruments and actors. Both public and private financiers can generally provide financial means in the form of equity, mezzanine or debt capital.

Not least because of the great importance of the regulatory framework, both aspects – energy policy instruments and financing in the managerial sense – are interrelated: The type and scope of the design of the financial requirement (e.g., the implemented support programs) directly influence the coverage of the financial requirements in the managerial sense (Figure 1Figure 1).

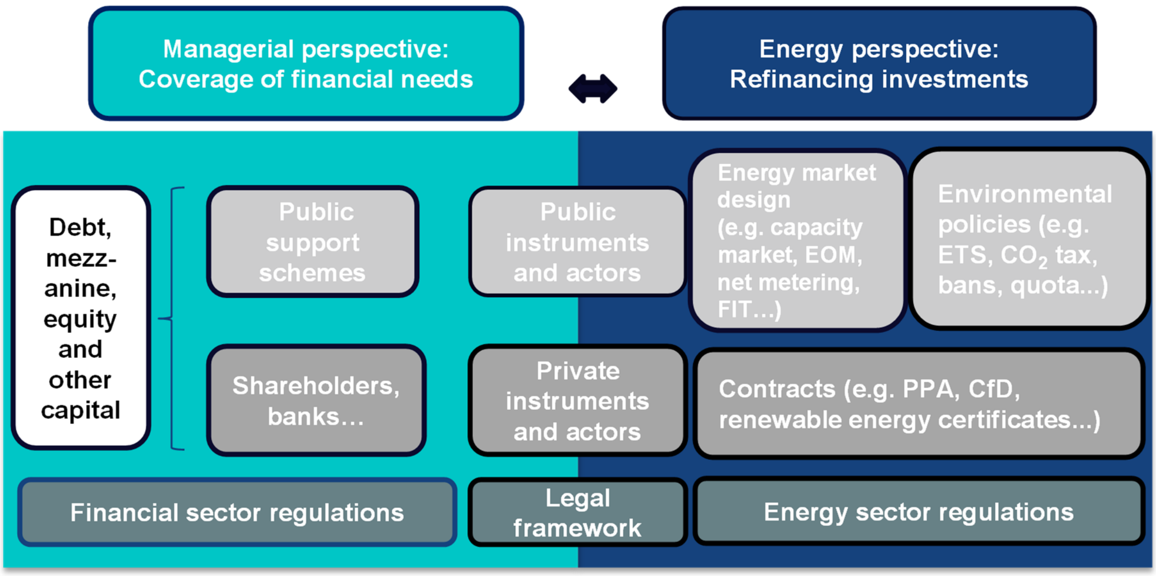

Figure 1: Financing Terms in the Context of the Energy Transition

Estimates of global financial needs differ in detail, but indicate the massive flows of capital needed to reach the global goals: The International Renewable Energy Agency (IRENA) estimates that the decarbonization of the global energy sector needs cumulative investments of at least US$ 110 trillion between 2018 and 2050 (IRENA 2018). Similarly, the International Energy Agency (IEA) states that more than US$ 2 trillion p.a. in clean energy investments are needed globally to “keep the door open for a 1.5 °C stabilisation” (IEA 2021). This would mean more than triple of the investments made in 2021. Clean energy investments would need to double to reach the 2 °C target (IEA 2021). According to HSBC, the world needs to invest US$ 6-8 trillion per year by 2030 to keep the global temperature rise below 2 °C, while current levels only amount to US$ 1 trillion p.a. at best (Klier 2019).

Against this background it is obvious, that efforts must be made at all levels to make the necessary investments to achieve the climate goals. A special role will be played by citizens, who will become part of the energy transition in various forms (referred to here as bottom-up models). This is also anchored, for example, by the European Union (EU) in the Clean Energy Package that aims at putting citizens at the core of the energy system (European Commission 2019).

The aim of this paper is to trace and illustrate the links between financing, energy and the current role of bottom-up models in financing of the energy transition. To this end, we review the literature on the relationship between energy and financing and group the identified papers into different strands that we preliminarily assign to “micro”, “policy”, “system” and “energy-to-finance” perspectives (Chapter 2), which include elements of all three approaches to the topic of financing outlined above (managerial, energy economic, regulatory). We then explore in some more details the literature on forms of financing in a managerial and in an energy economic sense (Chapter 3) and on the regulatory framework of the energy and financial sectors (Chapter 4). We conclude with a description of the link between the different facets described and the description of the respective research gaps that need to be addressed in the future (Chapter 5).

2 Relationship between finance and energy – a literature review

In the following, we will review the existing literature on the relationship between financing or finance and energy, highlighting especially how finance impacts on the energy sector and its development. We will take up specific aspects and strands of the literature in some details in the following two chapters. The idea is to provide the basic vocabulary and typologies needed for work in this area and to work out some relevant research gaps that need to be addressed.

2.1 Overview of perspectives on energy and financing

We use the term “financing” rather than “finance” because the focus is on the process, including forms of and actors involved in, obtaining the funds necessary to implement renewable energy installations, especially those developed by bottom-up models”. Finance, in turn, is the term used for a branch or sub-discipline within economics. It may also denote “the system that includes the circulation of money, the granting of credit, the making of investments, and the provision of banking facilities" (Merriam-Webster, Inc. 2022). The perspectives discussed in the following are related either to the sub-discipline of finance, especially using models developed within neoclassical finance, or to the financial system using different disciplinary approaches. A further distinction is to be made between financing and investing or investment: While financing is the act of raising or providing funds, investing refers to the reverse process of giving funds, i.e. an activity that starts with a payout and causes inflows in the future. Ultimately, investment means financing with a negative sign (Kruschwitz and Lorenz 2019). Depending on the issue at hand, we will therefore use either of the two terms.

Several other authors have reviewed the energy and finance/financing literature in the past (Elie et al. 2021; Hall et al. 2018; Steffen and Schmidt 2021; Zhang and Ji 2022). In our review, we identify four perspectives on this topic (cf. Table 1): micro-level perspectives, policy perspectives ("sustainable finance discourse"), system-level perspectives and literature studying the effects of developments in the energy sector on financial markets ("energy-to-finance"). These perspectives, topics and keywords displayed in the table will be explained briefly in the following sections.

Table 1: Strands of the literature on the relation between energy and financing

Level/ Perspective	Topic	Selected keywords
Micro-level perspectives	Forms of financing & RE investments	Overview: "Global Trends" reports Project finance/financing "Leveraging" private capital, blended finance Renewable energy as specific asset class
	Role of different financial market actors	
	Cost of capital, interest rates & energy modelling	
	Technology innovation phases	R&D financing
Policy perspectives	Policy instruments	
	Sustainable finance policies	Disclosure Green supporting factor Climate & monetary policy Green budgeting

Level/ Perspective	Topic	Selected keywords
System-level perspectives	Financing flows	Financing needs Funding gap, "Valley of Death" "Climate investment trap"
	Impacts of (financial) crises	
	Finance & innovation	Growth literature: financial development → technology innovation
	Finance & transition	Finance-related mechanisms to path dependence, carbon lock-in
	Co-evolution	
Energy-to-Finance	Asset prices & access to finance	Climate risks → stock returns Energy efficiency → access to external financing
	Financial stability	"climate Minsky moment" "sunrise" & "sunset industries" "Green Swan"

2.2 Micro-level perspectives

On the micro-level, we can distinguish at least four different strands, i.e. literature

1. on the forms of financing,
2. on the role of different actors in financial markets,
3. on cost of capital and interest rates, results of which are used to define parameters in energy models, and
4. on the relation between specific technology innovation phases and forms of financing or the lack of funding on specific stages of technology development.

The first strand mentioned reviews general financing structures (Krupa and Harvey 2017; Wiser 1997) or concentrates on project finance as a standard form of financing (larger-scale) renewable energy projects (Kayser 2013; Mills and Taylor 1994; Raikar and Adamson 2020; Steffen 2018). According to global statistics, project finance made up 35 percent of renewable energy asset finance in 2019 compared with 16 percent in 2004 (Frankfurt School of Finance & Management 2020). So while Steffen (2018) highlights the importance of project finance, Ameli et al. (2021a) conclude that the majority of projects in the renewable energy sector is still financed via corporate finance. Different financing structures and characteristics make renewable energy investments a distinct asset class from fossil-fuel or energy utility company stocks (Ameli et al. 2021a). Due to risk-return characteristics and the long-term investment horizon, private investors may be reluctant to invest in specific segments of the renewable energy market. Hence, there is a discussion about “leveraging” private capital flows with international public climate finance; this mix of private with public funding is also called “blended finance” (Deleidi et al. 2020; Owen et al. 2018). Moreover, project sponsors may use public-private partnership (PPP) structures to allocate risks so that these are acceptable for all financiers (Fleta-Asín and Muñoz 2021; Kaminsky 2022). Lastly, “green bonds” are discussed as a potential source of (re-)financing for renewable energy projects, e.g. in the Global South (Banga 2019).

On the actor side, two lines of research dominate: Some researchers have looked into the role of the banking sector and how it influences entrepreneurial and institutional investors’ activity (Alonso 2020; Geddes et al. 2018; Steffen et al. 2020). The focus could be on the banking sector generally, including requirements that banks ask from projects and stakeholders so that they can finance the projects – subsumed under the term “bankability” (Arezki 2021) – or on specific banks such as state development banks (Geddes et al. 2018). Other researchers investigate motivations of investors (Chassot et al. 2014; Salm et al. 2016), including citizens in the case of community energy initiatives (Bauwens 2016; Ebers Broughel and Hampl 2018; Holstenkamp and Kahla 2016).

Third, several authors have looked into the costs of capital and interest rates associated with renewable energy investments. Usually, they apply a Weighted Average Costs of Capital (WACC) approach (Hirth and Steckel 2016; Steffen 2020; Sweerts et al. 2019). Extensions include financial learning models (Egli et al. 2018). Related to this are papers that discuss parameter choice in energy modelling. In standard applications, authors often simplify financial relations and use parameters such as the costs of capital uniformly for all technologies and countries (Egli et al. 2019). Polzin et al. (2021) illustrate that different costs of capital for different countries lead to different optimal solutions.

Fourth, the innovation finance literature has worked out that certain phases in the innovation chain relate to specific financing needs and forms of financing (Polzin 2017; Polzin et al. 2016). In this context, much has been written on research and development, less on deployment and diffusion (Mazzucato and Semieniuk 2018). Descriptive and policy-related work such as the “Sustainable Energy Financing Continuum” with the “UNEP Triangle” (Reed and Gutman 2011) leads into the systemic perspective and the research on funding gaps discussed below.

2.3 Policy perspectives: sustainable finance debate

Besides the micro-level perspectives, there are different strands in the literature looking into financial market developments and financial policies, studying their effects on the energy sector. For some years now, this literature has centered on the term “sustainable finance”. At the core of the current sustainable finance debate, the underlying assumptions seems to be that disclosure exerts observe an influence on private capital allocation towards low-carbon assets (Ameli et al. 2021b). With Ameli et al. (2021b), we can call this the “Carney approach” after the former governor of the Bank of England. According to this line of research and finance practice, transparency, i.e. information on all climate-relevant aspects of businesses, helps capital markets to allocate financial assets efficiently in a climate-friendly manner. The main idea is that carbon-intensive ideas represent a (climate) risk to the investors. Contrary to this, low-carbon investments offer profit opportunities.

In efficient markets, rational investors would therefore divest from high-carbon and invest in low-carbon assets. However, both the efficient market hypothesis and the "capital switch" hypothesis are controversial (Ameli et al. 2021b; Fama 1970; Malkiel 2003; Grossman and Stiglitz 1980).

Besides disclosure, sustainable finance policies include, among others (Ameli et al. 2021b):

– The introduction of a green supporting factor (Dafermos and Nikolaidi 2021; D'Orazio and Popoyan 2019; Nicol et al. 2018),
– the introduction of climate considerations into monetary policy, i.e. central banks' asset purchases (Dafermos et al. 2020; Dikau et al. 2021), and
– green budgeting frameworks and tools (Petrie 2021).

Besides work on "sustainable finance", an older strand in the literature looks at and compares policy instruments. We will discuss this strand of literature in some more details in the following chapter.

2.4 System-level perspectives

The third group of literature that we identified are strands that look at finance and energy on a system or sector level. There is certainly an overlap with some papers subsumed under micro-level perspectives that observe aggregates and with papers included under policy perspectives. Nevertheless, we build a separate group with five strands:

1. Literature on financing flows (financing needs, funding gap),
2. works that analyze the impact of economic crises on energy financing/investments, especially the financial crisis of 2007 or currently the COVID-19 pandemic,
3. investigations of the relation between financial development and technological innovation,
4. analyses of the role of finance in transition processes, and
5. literature on the co-evolution of both, financial and energy sectors.

The first group of papers and reports investigates financing flows and estimates financing needs for the whole energy sector such as the investment needs outlined in the introduction. The "funding gap" literature usually highlights the specific characteristics of renewable energy investments, with especially the high upfront costs. In less developed financial markets, these pose a specifically severe problem, which is why a large part of this strand focuses on developing countries (Bazilian et al. 2014; Chirambo 2016; Schwerhoff and Sy 2017). Here, different policy measures are discussed, especially in the context of international initiatives, such as a multilateral guarantee mechanism (Matthäus and Mehling 2020). If not enough capital flows into the transition of the energy system in developing countries, this may put them into a trap (Ameli et al. 2021a). From an innovation finance perspective, gaps have been identified regarding certain stages of technology development. Auerswald and Branscomb termed this gap the "cash flow valley of death" (Auerswald and Branscomb 2003).

Second, there are works that look into the impacts of economic crises on financing the transition of the energy sector generally and renewable energy investments in particular. The financial crisis of

2008, for example, led to a general decrease in private investments in renewable energies, compensated by public stimulus packages (Arent et al. 2011; Bartlett et al. 2009; Mazzucato and Semieniuk 2018; Mundaca and Luth Richter 2015; Schwabe et al. 2009). Moreover, private investors' policy preferences changed (Hofman and Huisman 2012). Impacts of the ongoing Corona crisis are still under investigation. Authors highlight, among others,

– disruptions in supply chains, changing policy foci, and the effect of stimulus packages and green finance policies (Eroğlu 2021; Hoang et al. 2021; Tu et al. 2021),
– short-run contractions and negative effects especially in developing countries (Hosseini 2020; Khanna 2021; Li et al. 2022), e.g. in India (Shekhar et al. 2021),
– but also potential medium-to-long-term positive effects on renewable energy development (Khanna 2021; Magazzino et al. 2021).

Lessons from the financial crisis of 2008 for post-COVID public policies are stressed (Blazquez et al. 2021). Economic crises may affect renewable energy financing in different ways: through the amount of money available, the conditions under which money is given to the projects and/or companies, and due to changing forms of financing which are available for these types of activities. The literature referred to above not only descriptively describes shrinking amounts invested into renewables, but also tries to explain the mechanisms behind the observed changes.

Third, several authors study the relation between general financial development and technological innovation in the energy sector (Brunnschweiler 2010; Le et al. 2020). As highlighted under micro-level perspectives, specific phases in the innovation cycle require specific forms of financing, which may or may not be available depending on the overall state of development of the financial sector in a certain country or region. Moreover, the findings of a positive relation between financial sector development and the deployment of renewable energies are underpinned by observations on available financing instruments, experiences with private finance, and public policy instruments as investigated by the "forms of financing" and "financing gap" strands.

Fourth, finance or financing has played only a minor direct role in transition frameworks. Geddes and Schmidt's (2020) article aims to change this picture. However, arguments linked to questions of financing have also been used before to explain the emergence of path dependencies and lock-ins (Dangerman and Schellnhuber 2013; Granoff et al. 2016; Stein 2016). "Investing" is also part of the Social-Ecological System (SES) framework and governance structures a main focus, but the financial sector and its activities are usually not explicitly investigated (but e.g. Holstenkamp (2019b)). Geddes and Schmidt (2020) use the Multi-Level Perspective (MLP) and integrate the financial sector and financial policy into this framework as a separate regime. They then investigate the interaction between financial regime and technology niche. Steffen and Schmidt (2021) briefly discuss how to extend transition frameworks in general and the MLP and TIS (Technology Innovation System) frameworks in particular to better capture the financial system.

Lastly, there is a strand of literature discussing the co-evolution of the financial and the energy sector (Hall et al. 2018; Hall et al. 2016): Depending on the structure of the financial system, forms of financing renewable energies differ. Through the financing process of these new types of projects and related learning processes, the financial sector develops. Hence both, renewable energy and financial sector, co-evolve. These evolutionary processes are also part of the analysis by Geddes and Schmidt (2020) with focus on interventions by state investment banks.

2.5 Energy-to-finance

Several papers study the effect of climate change and developments in the energy sector on the financial sector, including feedback loops. The major focus in those papers is on financial market developments and financial stability. A first group of papers looks into the effects on asset prices and access to finance. Venturini (2022), for instance, researches the relation between climate risks and stock returns. Brutscher et al. (2021) investigate the effect of energy efficiency on the ability of a firm to obtain external financing.

The second group of works is more policy-oriented. Hence, there are links to the policy perspectives described above. This strand of the literature analyzes the effects of climate risks on the stability of the financial sector (Battiston et al. 2017; BIS 2021; Christophers 2017; Monasterolo et al. 2022). The causal chain runs from climate risks and their effects on asset prices to a slump down of (sub-)sectors or “sunset industries” (Semieniuk et al. 2021), which may endanger financial stability. Carney (2015) called a climate-induced financial crisis a “climate Minsky moment” after financial crisis theorist Hyman Minsky following his “financial instability hypothesis” (Bhattacharya et al. 2015; Minsky 1977; Vercelli 2011). More recently, the risk from rapidly rising “sunrise industries” has been highlighted, a phenomenon termed “Green Swan” (Bingler and Colesanti Senni 2022; Bolton et al. 2020).

3 Overview of financing instruments

In this chapter, we take up the different perspectives of financing described in the introduction referring to both energy-related and managerial-related financing (cf. Figure 1). At this point, both terms are again described in detail, an overview of the most common instruments is given without the claim of completeness and the importance of different financing instruments for bottom-up models is discussed.

3.1 Managerial financing instruments

Financing in the managerial sense refers to the coverage of capital requirements for making an investment. The capital requirements can be covered in various forms. There are multiple forms of distinctions that can be made. One is the distinction between debt and equity (Brealey et al. 2017). Debt providers often receive a fixed interest rate and repayment over a defined period of time. They do not participate in profits or losses and do not have any decision-making rights. Control rights are typically limited to information or specific covenants. Senior debt is paid back first in case of bankruptcy. The debt contract constitutes an obligation. Examples include bank loans, promissory note loans and crowdlending (Holstenkamp 2020; Sedlitzky and Franz 2019). In the case of equity, on the other hand, investors become shareholders in the company. Equity contracts thus constitute ownership with according decision-making, voting rights and rights to information. Equity-holders participate in profits and losses (Holstenkamp 2019a). In addition, there are also mixed forms called mezzanine capital, which are characterized by the fact that they cannot be clearly assigned to either equity or debt, but contain elements of both. These include preference shares, profit participation certificates, convertible loans and subordinated loans, to name just a few forms (Holstenkamp 2019a; Holstenkamp 2014; Pratt and Crowe 1995).

Another distinction is the one between project finance and corporate finance. In (non-resource) project financing the coverage of capital requirements is only based on cashflows and assets of the project whereas corporate financing takes the assets of the corporation into account (Esty 2004; Holstenkamp 2020; Nevitt and Fabozzi 2000; Yescombe 2014). Project finance is typically used for medium- and especially large-scale renewable energy projects (Steffen 2018). The financial model is usually built on a long-term contract with a reliable and solvent offtaker in power purchase agreements or long-term and secure feed-in tariffs. In those cases of stable and relatively secure cashflows project financing is often available at (relatively) favorable terms not only for projects of large investment volumes. In the bioenergy sector, agricultural input prices typically fluctuate. Due to these supply risks, non-recourse financing is typically not available. Rather, elements of corporate finance are integrated into the financial structure (Degenhart and Holstenkamp 2011; Fischer 2015). Similarly, newly developing energy markets, e.g. for ancillary services, and changing business models make it necessary to adapt financing models – probably including elements known from early-stage financing. As markets are just evolving, to our knowledge, this issue has not yet been explored in detail in the scientific literature.

3.1.1 Public support schemes

In terms of sustainable finance, it can be in the government's interest to stimulate investments in renewable energy plants. Various instruments are available for this purpose. For example, governments can provide subsidies. Subsidies are financial government assistance that companies, other states or private households can receive and are not tied to a direct counterpart contribution (Buhr 2022). Subsidies can be provided for example in form of direct public investment if not done at non market rates, grants, concessional loans, public guarantees to ease the cost of financing investments in certain technologies (Holstenkamp 2020). An example of this are subsidy programs such as the federal promotion of energy and resource efficiency (“KfW-Förderung”), which provides companies with concessional loans for investing in highly intelligent technologies (KfW 2022).

While subsidies and rebates are claimed in advance of an investment, production tax credits and investment tax credits can also have a cost-reducing effect elsewhere. The production tax credit is a tax incentive that provides the investor or owner of a qualifying property or facility with a tax credit based on the amount of renewable energy (electricity, heat or biofuel) generated by that facility. An example for that would be the Renewable Electricity Production Tax Credit in the US. It is a per kWh federal tax credit included in the US tax code for electricity generated by qualified renewable energy resources (EPA 2022). There is a price difference between different energy sources. For electricity generated from landfill gas, open-loop biomass, municipal solid waste resources, qualified hydroelectric, and marine and hydrokinetic, the tax credit is 1.3 cent/kWh (EPA 2022). For other sources like wind, closed-loop biomass and geothermal resources, it is even higher with 2.5 cent/kWh (EPA 2022). Whereby the investment tax credit is a fiscal incentive that allows investments in renewable energy to be fully or partially credited against the tax obligations or income of a project developer, industry, building owner, etc. (REN21 2020). Typical investment tax credits are tax credits for solar investments or for research work (Netinbag 2022). In the US, it is possible to get an investment tax credit as high as 30 percent of the cost of capital for renewable energy projects. The tax credit vests rateably over a five-year period (Reuters 2022). If a project is sold in that five-year period, the unvested portion of the investment tax credit is subject to recapture (Reuters 2022).

3.1.2 Financing from private actors

In addition to the public support schemes outlined in the previous section debt and equity can be provided by natural persons or companies.

On the part of private banks, the importance of sustainability aspects is increasing. More and more banks have established themselves whose brand core is dedicated to sustainable finance (“environmental”, “ethical”, “value-based” banks). But conventional banks are also including more and more investment opportunities in sustainability aspects in their portfolios, e.g. sustainable ETFs, environmental investment funds or ESG bonds, partly driven by growing demand for sustainable investment opportunities, partly by regulation.

The form in which capital can be collected from natural persons and corporate identities varies. In addition to the issuance of company shares of a limited company over-the-counter or stocks of a corporation via stock exchanges, the raising of capital via crowdfunding has also become increasingly popular in recent times. In crowdfunding, a project or venture is financed by raising money – often relatively small individual amounts – from a relatively large number of people ("crowd") using an online platform. The money raised through crowdfunding does not necessarily buy the lender a share in the venture. Some types of crowdfunding reward backers with an equity stake, structured payments and/or products that were financed by the crowd (REN21 2020).

3.2 Energy-related financing instruments

The energy economic understanding of financing can be divided into three categories. On a public level, the regulation of energy markets and the design of the market have a massive impact on the possibility of refinancing investments. In addition, environmental policies in general play a more indirect role in the refinancing of investments. On another level, there are private instruments that contribute to the refinancing of investments in the form of contracts. Of course, the legal framework set at the public level has a massive influence on the private level.

3.2.1 Environmental policies

Environmental policies serve to protect the environment. This includes all measures from prohibitions of environmentally harmful behavior to financial support for environmentally friendly investments (Benson and Jordan 2015). The regulation of the energy market design, including the framework conditions that enable the refinancing of investments through renewable energy plants, also falls under the term environmental policies, but will be examined in more details in the next section.

At this point, we will briefly discuss policies that are indirectly attributed to the area of financing, because they monetarise negative externalities. Effectively, the instruments change the relative price of renewables compared to energy produced by conventional power plants. Hence, investments in the sense of a transformation of the energy system are more attractive.

The establishment/expansion of an Emission Trading System (ETS) compared to the establishment of a CO_2 tax has been lively discussed in the past. The EU ETS is characterized by the cap-and-trade system with some minor baseline-and-credit elements. Here, the required certificates can be purchased either on exchanges or **over-the-counter**. In particular, certificate trading over-the-counter becomes lucrative for companies as the cap falls and market prices thus rise, contributing to refinancing projects that need less or save CO_2 emissions. In Germany, the CO_2 tax represents an extension of the European ETS in the sense that the heat and transport sectors will also be priced within the framework of a national ETS from 2022 onwards, starting with fixed prices from 2022 to 2025 and a corridor in 2026 **(BMWi 2019; Bundesregierung 2022)**. Hence, it increases the costs for carbon-intensive forms of electricity generation and heating and makes renewable energy projects more competitive investment alternatives. Table 2 summarizes some of the discussed advantages of an ETS and a CO_2 tax, respectively.

Table 2: Advantages of ETS and Carbon Tax

Advantages ETS	Advantages Carbon Tax
Higher environmental accuracy when setting an ideal CO_2 price is not possible **(Agora 2022; FIS 2011)**	Faster implementation possible and better controllability of revenues (Agora 2022)
Higher cost efficiency than carbon tax **(FIS 2011)**	Transaction costs for implementation, control and sanctioning lower than ETS (FIS 2011)

The situation is similar with prohibitions and statutory minimum requirements. These can mean that investments in certain areas are no longer permitted. The European taxonomy, for example, stipulates that operators of gas-fired power plants should switch from fossil gas-related activities, to lower CO_2 electricity generation by 2035 (European Commission 2022). Even if this does not contribute to refinancing of renewable energy power plants directly, these measures are important in the energy system transformation and could lead to conventional power plants being forced out of the market enabling higher revenues by renewable technologies.

Similar to the bans, there is the possibility to set minimum requirements for certain areas via quotas, obligations and mandates. In essence, the government obliges consumers/suppliers/generators to provide or use a predetermined minimum target of renewables (REN21 2021; REN21 2020). This can also lead to improved competitiveness of renewable energy sources (RES) plants and yield direct revenues for selling quotas if these are tradable.

3.2.2 Energy market design

Refinancing the investment in energy production facilities depends heavily on the energy sector regulations. While in 3.2.1 the focus was on environmental policies that lead indirectly to more investments in RES, this chapter focuses on public instruments and the implemented energy market design that refinances investments in RES through income generated after investment into RES. Main source for refinancing investments is the remuneration of produced electricity. However, especially with a growing share of renewables also the provision of flexibility - provision or absorption of energy on demand - is gaining importance.

One distinction that can be made is between an Energy Only Market (EOM) and a capacity market. In an EOM only the electricity generated is remunerated. The energy is traded either via bilateral business relationships (over-the-counter, OTC) or the power exchange (Next Kraftwerke 2022a). In a capacity market model, the energy generation capacity is remunerated. Whether the produced energy actually has to be produced is irrelevant (Next Kraftwerke 2022b).

Nevertheless, there are hardly any energy markets in place that follow solely one of these principal market designs. For example, in Germany in general an EOM is established and electricity is traded on the power exchange or OTC. Additionally, for some RES tenders determine the renumeration of produced electricity before investment for a fixed period of time. A tender is a procurement mechanism by which renewable energy supply or capacity is competitively solicited from sellers, who offer bids at the lowest price that they would be willing to accept. However bids may be evaluated on both price and non-price factors (REN21 2020). However, in Germany there are also elements of a capacity market model in place when for example in case of the control energy market providers are renumerated for the guarantee to provide or take an a priori agreed amount of electricity for a certain period of time.

Besides market driven elements of the energy market there are also non-market driven elements implemented by legislation. For example, in the case of a feed-in tariff, there may be a fixed degression, as it is the case for smaller PV systems up to 10 kWp in Germany, which determines a tariff for the first 20 years of system operation based on the number of new installations (cf. § 49 EEG 2021).

Table 3 lists some of the most common instruments and their international diffusion. Different instruments can also be used for different areas or plant sizes within the same market.

Table 3: Energy Industry Financing and Funding Instruments

	Explanation	Distribution
Feed-in tariff (FIT)	“A policy that typically guarantees renewable generators specified payments per unit (e.g., USD per kWh) over a fixed period” (REN21 2020, p. 255).	Existing on national level in 72 countries and in five countries on sub-national levels (REN21 2021)
Feed-in premium (FIP)	The feed-in premium is a payment to operators of renewable electricity generation plants that compensates for the difference between the wholesale electricity price and the plant-specific levelized cost of electricity (Next Kraftwerke 2021).	
Net Metering/ Net-Billing/ Virtual Net Metering	A regulatory framework in which self-generated energy fed into the grid is offset against electricity purchased from the grid. Depending on the structure of the framework, any surplus electricity is (proportionately) remunerated, credited to the next billing period or fed into the grid without remuneration (REN21 2020; SWH Group 2021). Virtual net metering also allows a group of prosumers to share generated electricity (REN21 2020).	Existing on national level in 58 countries and in six countries on sub-national level (REN21 2021)
Market Concession Model	“In a concession model a private company or non-governmental organization is given the exclusive obligation to provide energy services to customers in its service territory, upon customer request“ (REN21 2020, p. 257).	
Auctions/Tender	A mechanism whereby sellers submit bids at the lowest price they are willing to accept. This can be for capacity or quantities of electricity (REN21 2020).	Existing on national level in 108 countries and in three countries on sub-national level (REN21 2021)

3.2.3 Contracts

The design of environmental policies and the energy market design also allow different instruments for the refinancing of generation plants by private actors. This applies, among other things, to direct marketing. In direct marketing, the electricity fed into the grid is sold on the electricity exchange or directly to selected customers, i.e. OTC, in Germany usually via the so-called “market premium model”. In Germany, a distinction is made between the mandatory direct marketing of new plants and the optional direct marketing of existing plants (Next Kraftwerke 2021). The mandatory direct marketing applies to plants with an installed capacity of 100 kW or more (§ 20 EEG 2021) that were commissioned on or after 01.01.2016. It is also mandatory that these plants can be controlled remotely. The only exceptions are renewable energy plants that were approved and commissioned before the EEG 2014 came into force, as well as biogas and biomethane plants. These must already market directly in the course of the EEG 2012, provided that the plant was commissioned before 01.01.2014 and has an installed capacity of more than 750 kW (Next Kraftwerke 2011). All plants that were connected to the grid before 01.01.2016 with an installed capacity lower than 100 kW have the possibility to voluntarily enter the optional direct marketing (Next Kraftwerke 2011). Financially direct marketing means, compared with a fixed FIT, that publicly regulated payments by the grid operator are exchanged for payments by a private non-regulated player. The “market premium model” ensures that plant operators get the average electricity price plus premium. Hence, the risk for financiers generally reduces to the solvency risk of the marketing company and costs for switching the partner.

In addition to the power exchange, however, contracts can also be concluded between generators and consumers that regulate the purchase of the electricity generated. In so-called off-take agreements, the conditions under which the electricity is sold are specified. A feed-in tariff (cf. Section 3.1.1) is also a type of off-take agreement in which the state guarantees the purchase of the electricity. On the private level, off-take agreements can be e.g. power purchase agreements (PPAs). In the PPA, prior to the construction of a renewable energy project or installation of renewable energy equipment between a producer of energy and a buyer of energy a contract to purchase/sell portions of the producer's future production is negotiated (REN21 2021; REN21 2020). The amount of the payment for the electricity to be purchased can be determined in advance. In recent years, the volume of concluded PPAs in the field of ground-mounted PV in Germany developed from one to two gigawatts annually in 2019 and 2020 to four gigawatts in 2021 (Zeigert 2021). In 2020, 90 percent of PPAs in Europe were concluded for wind turbines, 8 percent for solar parks and 2 for other technologies (PwC 2020). By 2023, 25 GW of PPA projects are already planned across Europe in equal shares in the wind and solar sectors (Ecke and Herrmann 2022). For financing from a managerial perspective, PPAs add additional risks and complexity, which affect form and terms of financing.

A variable payment can also be applied within the framework of a contract-for-difference (CfD). In a CfD positive and negative deviations from a fixed reference price are paid out to the contracting party. In this context, it is also referred to as a symmetrical market premium (Next Kraftwerke 2021).

In addition to trading the electricity generated, it is also possible to trade certain characteristics of the electricity generated if the appropriate legislation is in place. For instance, similar to the tradable emission certificates (cf. Section 3.1.1) it is possible to establish a market for renewable energy certificates or regional certificated electricity. Utilities can purchase these certificates to meet quotas or to offer customers certain characteristics of the electricity even if the corresponding green generation capacities are not available in the portfolio of the utility. Renewable energy certificates exist in 31 nations and in one nation on sub-national level (REN21 2021). In Germany, electricity renumerated via EEG lose their green status and hence, only renewable energy certificates from power plants in the other direct marketing can be traded.

3.3 Importance of financing instruments for bottom-up models

In this section, the financing instruments described are analyzed with regard to the current relevance for bottom-up models.

From a managerial perspective, project financing is highly relevant with respect to bottom-up models since bottom-up models are often founded for a special purpose or project. Hence, in case of the investment in a RES production facility cashflows of the installed RES production facility must refinance CAPEX and OPEX. With a growing number of established bottom-up models, corporate finance becomes growingly important when bottom-up models are well established and start operating multiple facilities.

Even though not directly generating cashflows for refinancing investments in RES, bottom-up models are also influenced by environmental policies such as the ETS and a CO_2 tax. In Germany the energy industry is integrated in the EU ETS and the mobility and heating sector is covered by the carbon tax introduced in 2021 (BMU 2022). Both increase the costs for energy produced with fossil fuels. Hence, bottom-up models focusing on the production and consumption of self-produced electricity might attract potential participants when alternative sources of energy become increasingly expensive.

From an energy-related perspective, non-market driven financing instruments have been of great importance for the development of bottom-up models (Bauwens et al. 2016). The predictability of cashflows and a minimum of uncertainty and complexity is of great importance because of high risk awareness of investors from local communities and the reliance on voluntary work (Horstink et al. 2020). Hence, in Germany established fixed feed-in tariffs determining the price for produced electricity for 20 years after installation are of utmost importance.

Even though in various countries there are different financing instruments implemented, there is no universal understanding which instruments help best to promote different types of bottom-up models. In Germany, for instance, the financial instruments highlighted in this section mostly target individual persons or actors. Enabling collective bottom-up models needs to be addressed and included in the legal frameworks as is being discussed in different EU member states in relation to the transposition of stipulations on energy communities in the recast Renewable Energy Directive. Research is needed showing the effects on the energy system of different financial instrument (but see e.g. (Grashof 2019)).

4 Legal framework of energy and financial sectors

This chapter discusses energy financing and regulatory frameworks from political and legal perspectives. Hence, it takes up the third approach (regulatory, next to managerial and energy economics approach) towards financing in the energy sector outlined in the introduction. Different nations around the globe have different policies and national strategies to achieve their goals of energy transitions (Hughes and Urpelainen 2015). The speed of achieving those goals depend on the regulatory frameworks, which “often act to increase returns, reduce risks, or stimulate new markets or sources of revenue. Policy instruments thus become coupled to financial mechanisms“ (Iskandarova et al. 2021, p. 3). While the focus in the energy-related literature usually is on regulation of the energy sector, we briefly also touch on the impacts that regulation of the financial sector has on developments in the energy sector – an aspect that has recently gained more attention following the attempt by financial regulators to integrate climate change considerations into rules for financial markets (Berenguer and Cardona 2014) (cf. also policy perspective in Chapter 2).

4.1 Regulating the energy sector – changes & challenges

Throughout modern history, the energy sector, especially electricity and natural gas, has always remained a highly regulated sector (Joskow 2014; Polinsky and Shavell 2007). The network character of the industry has often been used as an economic justification for a monopolistic market design (Künneke et al. 2005). Political changes together with developments in economic theory (“contestable markets”) have led to liberalization and deregulation of the energy sectors, which, in turn, led to the emergence of new actors at national, sub-national and local levels (Finger and Jaag 2016; Iskandarova et al. 2021). Besides these changes in the understanding of energy policy, technological progress has also led to an increasingly decentralized structure, especially of the electricity sector. In addition to progress of renewable energy technologies, digitalization may contribute to these developments (Baidya et al. 2021; Di Silvestre et al. 2018; Loock 2020).

The regulation of the energy sector and the developments of energy policies have been intensively discussed in the literature. This includes changes in the use of policy instruments as outlined in Section 3.2. Transition challenges have been worked out using different theoretical approaches and frameworks (Cherp et al. 2018; Foxon 2013; Foxon et al. 2010; Geels et al. 2017; Geels et al. 2016; Judson et al. 2020; Markard 2018; Markard and Hoffmann 2016). Any analysis of changes in the regulatory environments can therefore relate to this broad strand in the literature.

The EU has recently put emphasis on individual and collective prosumers and energy communities with the “Clean Energy Package”, the directives of which were supposed to be transposed into national laws until 2021. With this switch in European energy policy, more attention is being placed on smaller actors (Coenen and Hoppe 2021; Lowitzsch 2018; Roberts 2019). We summarize these different entities in the following under the term “bottom-up (energy) models”. As they are the focus of political and legal analyses in the research group, we discuss them separately in the following section.

4.2 Bottom-up models & regulation

In the literature, one finds a plethora of different concepts that we summarize as bottom-up models. These concepts are not identical, but interrelated:

- **Energy Communities**: The “Clean Energy for All Europeans” legislative package (short: “Clean Energy Package”) has introduced “energy communities” in two variants, namely “renewable energy communities” (RECs) and “citizen energy communities” (CECs). RECs and CECs are both open and voluntary initiatives. These initiatives are owned by locals with the primary aim of generating social and environmental benefits rather than profit maximization. However, RECs differ from CECs on the issue of geographical coverage, autonomy, participation and activities of energy production. RECs are limited to the location or region of the plant site, whereas members of a CEC can be spread more widely. RECs deal with the generation of electricity from renewable sources, CECs can take any activity in the energy sector in general (cf. recast Renewable Energy Directive, Art. 22, and Electricity Directive, Art. 16). Energy communities may include not only local citizens, but also local authorities and small and medium-sized enterprises (SMEs). Since 2016, the concept has been studied more intensively in the academic literature.
- **Community Energy:** A very common concept in policy discussions and the academic literature (Berka et al. 2020; Berka and Creamer 2018; Creamer et al. 2018; Creamer et al. 2019), there are various related terms used for “community energy” – in German “Bürgerenergie” and in French “énergie citoyenne“. It is, for instance, also called “citizen energy ownership” or “community power” (European Commission and Directorate-General for Energy 2019). There have been various attempts to define community energy, the definition by Walker & Divine-Wright (2008) most probably being the one most widely cited. According to them, community energy is any project or initiative where people have ownership (community involvement) or a meaningful say in the running of renewable energy or energy-related services for a collective benefit sharing. In the Anglo-Saxon literature on community energy there is a distinction made between “communities of locality (or: place)” and “communities of interest”. In essence, the RECs are communities of locality, whereas CECs could also be communities of interest only (Bolinger 2001; Walker and Devine-Wright 2008).
- **Local Energy Initiatives:** Local energy initiatives is a term that is often used in recent studies on the Dutch energy transition (Hasanov and Zuidema 2018; Hisschemoller 2012; Warbroek and Hoppe 2017). Devine-Wright has worked on the difference between community energy and local energy, elaborating that the focus in UK policy has shifted from the former to the latter. Hall et al. (2016) use a somewhat related, but in details different concept that they call “civic energy”, encompassing community energy and municipal utility companies. Thus this concept slightly differs from the use in the Dutch literature on local energy initiatives, but especially from Devine-Wright’s understanding of “local energy” as the latter has a focus on partnerships and the private sector (Hall et al. 2016; Walker and Devine-Wright 2008).

– **Prosumers (self-consumers/self-generators):** These are households that own and operate renewable energy and storage installations and directly use the electricity generated (Campos et al. 2020; Sousa et al. 2019). The Clean Energy Package distinguishes between “self-consumers” and “jointly acting self-consumers”, i.e. collective forms of prosumerism. Prosumerism has attracted some attention not only by practitioners following EU legislation, but also in the academic literature (Brown et al. 2019; Müller and Welpe 2018; Günther et al. 2019). However, work often focusses on single households, as this is the “basic form” and probably the most common variant of prosumerism. The concept of collective prosumerism is somewhat close to, even if not identical with, community energy (Campos et al. 2020).
– **Peer-to-Peer:** This is defined as a business model, in which an online platform – often with the help of blockchain technology – serves as a marketplace where consumers and producers meet to trade electricity (IRENA 2019). In work on peer-to-peer energy models, scholars often focus on the technological aspects (Almeida et al., 2021; Sousa et al., 2019). It is a business model that could be used by community energy groups or citizen energy communities.

While this list is not exhaustive, it contains the major concepts of (collective) bottom-up models that are studied here.

The relationship between these bottom-up models and the regulatory framework has been subject of various studies. Scholars refer, for instance, to Denmark, Germany, Great Britain and the Netherlands as examples (Wierling et al. 2018). Each country has its own experience, but studies show that there are some common features, e.g. community activities and collective action, among energy cooperatives in Europe (Wierling et al. 2018). These models are considered as enablers of energy transitions (Gui and MacGill 2018). Regulatory frameworks, overall institutional environment, and proper knowledge play a central role in the energy transition (Wierling et al. 2018). There are insights from studies on factors that determine the shape and size of this sector in different places (Bolinger 2001; Campos et al. 2020; Gui and MacGill 2018). Most of the studies concentrate on a small sample of countries such as those mentioned above (Campos et al. 2020; Gründinger 2017; Löhr 2020; Thiel et al. 2019) or are single case studies (European Commission and Directorate-General for Energy 2019; Walker and Devine-Wright 2008; Wierling et al. 2018) focusing on parts of this sector and using different theoretical approaches.

Against this background, there is a need for investigations beyond well-known country examples, for comparisons of a larger set of cases (“large n”) that help to work out general findings on social mechanisms, which lead to the emergence and growth of bottom-up models, and on the transferability of findings between countries, especially to the Global South.

4.3 Financial sector regulation and its impact on the energy sector

Compared to energy market regulations, the regulation of financial markets has received less attention by energy researchers, with the exception of papers on sustainable finance that we assigned to the policy perspectives in Section 2.3. This strand of the literature puts financial regulation and its impact on the energy transition into the focus of practitioners and researchers. The main idea is to legally enforce and push the financial sector into financing sustainable developments, e.g. the transition of the energy sectors. Besides, financial sector regulations also play a role in other works on what we call system-level perspective, even if it is usually not the focus. Occasionally, related areas of law, such as company law, also come into view (Dangerman and Schellnhuber 2013).

Other examples of the influence that financial market regulation can exert on developments in the energy sector include interactions between financial participation of citizens in the energy transition and consumer protection laws: In 2011, the EU introduced the Alternative Investment Fund Manager (AIFM) Directive. It was to be transposed into national laws until 22 July 2013. In Germany, it led to the introduction of the German Capital Investment Code [Kapitalanlagegesetzbuch, KAGB]. Applicability of the law to different forms of community energy companies and different types of projects of these community initiatives was unclear at the beginning. This led to high uncertainty in the sector and caused many initiatives to retract from developing their projects (Holstenkamp 2014). This case illustrates potential trade-offs that exist between enabling active participation of citizens in the energy transition and consumer protection. Risk management regulations (Gaumert 2019) that may restrict the financing of small actors, including energy communities, are another example of these trade-offs, which need further investigation.

5 Bottom-up models: Links between actors and their behavior, instruments, legal framework and existing research gap

The previous chapters showed the importance of different facets concerning financing of bottom-up models and the existing research gaps.

– Actors and their behaviors: There are at least some studies looking into the types of financial market actors involved in energy financing, especially financing of bottom-up models, and their behaviors, also some – even though not many – studies which investigate effects on the energy transition process. This said, there more research in this direction is needed to substantiate first findings from these research strands.
– Instruments: Various financial instruments from a managerial and an energy perspective are in place. However, focusing on Germany there is no clear understanding, which overall system effects arise of the various instruments.
– Legal framework: Effects of legal frameworks on the form and number of bottom-up models have been researched in the past, but for a selection of geographies only or mainly and mostly in single case studies or for few countries in comparative analyses. Moreover, financial market regulations and their effects on bottom-up models are underresearched.

These different facets cannot be fully understood when analyzing them separately. Even though addressing different perspectives and understandings of “financing” in the energy context (cf. Chapter 1) there are also several logical links that need to be observed in relation with one another:

– The behavior of financial market actors (Chapter 2) and their response to changes in financial instruments (Chapter 3) have effects on a system-level.

- Forms of financing (Chapter 2) and financial instruments (Chapter 3) need to be implemented in the current legal framework (Chapter 4) and the development of further financing structure of bottom-up models be researched.
- The political legal perspective (Chapter 4) of the past energy and financial sector development influence massively the implementation possibilities from insights of an energy system model from a techno-economic perspective of financial instruments (Chapter 3).

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