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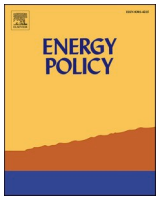

Regulatory state capacity for accelerating net-zero transitions: Lessons learned from governing electricity storage in Germany

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ABSTRACT

Policy implications arising from the unique challenges in the acceleration phase of net-zero transitions are receiving increasing attention. As a refinement, this paper focusses on regulation as a subset of policies and investigates the regulatory implications of such acceleration challenges. We integrate the literature on transformative policy capacity for conceptualising regulatory state capacity needed for responding to these challenges through regulatory change. This regulatory state capacity is operationalised by means of roles, abilities and resources. We apply our analytical framework to the market for electricity storage systems in Germany. Based on in-depth interviews and participant observation we find a high institutionalisation and complexity of regulation, and an accelerating effect of multi-system interactions on and contestation around regulatory changes. Our research reveals that in Germany regulatory state capacity has been characterised by a high relevance of gatekeeping and moderating as well as political abilities in light of the challenges 'whole system change' and 'expansion and contestation'. We further observe a change in roles, from a maintaining to a creating character, and different sources of more radical regulatory change: while the changing attitude towards residential storage in the regulatory agency is based on learning and reflexivity due to its role as observer, warner and mitigator embedded in a changing socio-technical environment, the changing regulatory state capacity in the investigated ministry is triggered by the change of government and the associated stronger political will from inside the organisation itself. In conclusion, the article provides recommendations for policy makers with a focus on regulation.

1. Introduction

The bulk of established research on energy transitions has largely focused on niche innovations, which challenge established regimes and emerge in tandem with closely associated developments such as the entry of new players or changes in businesses models, value chains, policies, and user practices (Araújo, 2023; Köhler et al., 2019). However, as such transitions progress, some technologies are moving to the next transition stage, when socio-cultural, economic, ecological and institutional changes accumulate and interact (Rotmans et al., 2001). In transition studies, this later stage is often referred to as acceleration phase of transitions, when niche innovations enter mainstream markets, widen their scope in geographical diffusion and advance into adjacent systems (Sovacool et al., 2025; Markard et al., 2020; Roberts et al., 2018). These developments trigger a redefinition of existing institutions along with significant contestation and resistance (Lindberg and Kammermann, 2021; Kivimaa et al., 2019; Roberts and Geels, 2019; Schot and Kanger, 2018).

Recent contributions have categorised challenges unique to this acceleration phase, namely 'whole systems change', 'interaction between multiple systems', 'decline and resistance', 'expansion and contestation', 'consumers and social practices', 'justice', 'international dynamics' and 'governance' (Sovacool et al., 2025; Rogge and Goedeking, 2024; Markard et al., 2020). These challenges might prevent the acceleration of transitions and require substantial efforts from multiple actors to address them, including from policy makers. However, the resulting policy implications remain vague and do not consider required capacities of policy makers to tackle such challenges, in particular regarding

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changing regulation. We close this gap in the literature by shedding light on the regulatory implications of the novel challenges in the acceleration phase of transitions, thus, contributing to a long-standing but somewhat side-lined debate on the role of regulation in transforming socio-technical systems (Blind, 2024; Raven et al., 2016; Smith and Raven, 2012; Geels, 2004).

Conceptually, we draw on the emerging literature on the role of governments, governing entities and civil servants in transformative change, along with their constraints and capacities (Borrás et al., 2024; Song et al., 2023; Borrás and Edler, 2020). In particular, we focus on state capacity required for regulatory change that addresses challenges arising in the acceleration phase of net-zero transitions, instead of maintaining the status-quo. Building on work of Borrás et al. (2024) and Wu et al. (2015), we introduce the term "regulatory state capacity", which we define as the roles, abilities and resources necessary to design and adopt regulatory changes required to tackle acceleration challenges.

Empirically, we provide new original insights from a particularly telling case, namely the market for residential storage systems in Germany with its energy transition being in the midst of the acceleration phase. As will be shown, residential storages present a suitable case for analysing acceleration challenges and required regulatory state capacities, since regulatory barriers challenge the further development and upscaling of more comprehensive business models including, for instance, grid services. Hence, we raise the following research question: *How do Germany's governing entities tackle the regulatory implications resulting from the acceleration challenges associated with the growing market for residential storage systems?*

The remainder of the paper is structured as follows. The next section presents the conceptual background of our study and outlines our analytical framework. After introducing our research design and case (section 3), we identify acceleration challenges and their regulatory implications in the market for residential storage systems in Germany (section 4). We show how governing entities respond to these challenges by analysing their roles, resources and abilities. In section 5, we discuss overarching regulatory implications, the features standing out for a high regulatory capacity and offer recommendations for policymaking. Section 6 concludes by discussing limitations of this study and future research lines.

2. Towards an analytical framework for investigating regulatory state capacity for accelerating net-zero transitions

In this section, we first introduce our key concepts, namely acceleration challenges, policies in general and regulation in particular, and capacities of governing entities. Drawing on these key concepts, we then outline our research framework applied to analyse the regulatory state capacity for accelerating net-zero transitions.

2.1. The role of policy in accelerating net-zero transitions

Transition scholars have identified several challenges associated with the acceleration phase of sustainability transitions. Markard et al. (2020) identified the following 'acceleration challenges' relating to the focal and adjacent systems: whole system change, interactions between multiple systems, resistance from declining industries, changes in consumer practices and routines, and coordination challenges in policy and governance. Drawing on the case of transport electrification in Germany and California, Rogge and Goedeking (2024) complemented these challenges by introducing three additional ones: expansion and contestation, international dynamics, and justice.

Both Markard et al. (2020) and Rogge and Goedeking (2024) identify policy makers as essential for accelerating transitions and derive relevant implications for policymaking (for details see Table 1). According to Markard et al. (2020), policymaking, first, needs to be more integral inducing changes in entire systems across domains instead of fostering single innovations. Second, a broad range of actors should engage in policymaking for nurturing social acceptance or forging supportive industry coalitions. Third, a stepwise applied, broad mix of policies (standards, incentives, subsidies, taxes) is required. Finally, particularities of different sectors and places need to be acknowledged. In addition, Rogge and Goedeking (2024) emphasise the need for responding to contestations in adjusting institutional frameworks, applying a broad justice approach as well as considering transnational policy feedbacks.

Table 1
Overview of different challenge types in the acceleration phase and their policy implications.

Acceleration challenge	Description	Policy implications
(1) whole system change (WHO)	Major changes in system: complementary interactions between multiple innovations, fundamental changes in system architecture	Focus on entire systems instead of singular innovations, support experimentation with socio-technical system change instead of sole focus on technological change
(2) multi-system interactions (MSI)	Increasing changes in the interaction of multiple systems, with a focus on tensions in multi-system interactions	Overarching, cross-cutting missions; non-compartmentalised, more integral policy making; multi-system task forces
(3) decline and resistance (DEC)	Decline of existing industries and businesses, and multi-actor resistance to such decline	Support structural change and reskilling of work force, create social acceptance, forge winning coalitions, compensate losers
(4) expansion and contestation (EXP)	Contestation around the expanding trajectory, incl. framework conditions for new mass markets, securing future market shares and gains	Update electricity market designs, regulate data access, set product and green finance standards, incentivise faster portfolio shifts to clean tech
(5) changes in consumer practices and routines (CON)	Major changes in consumer practices and demand patterns	Stimulate technology adoption, behavioural change and learning-by-using processes; enable new business models; adjust planning
(6) justice (JUS)	Multi-dimensional justice implications of system changes and affordability of new technologies for low-income households	Include a broad justice approach in policy design and evaluation, tailor policies to low-income households
(7) international dynamics (INT)	Global interplay driven by international competition, pioneering countries, geopolitical risks, changes in global value chains	Renewed focus on green industrial policy, strategic resource partnerships, free trade clubs among like-minded partners
(8) governance (GOV)	Increasing complexity of governance, policy paradigm change towards greater policy intervention	Stronger vertical and horizontal policy coordination, governance reform, designing policy mixes for creative destruction, policy sequencing

Source: Rogge and Goedeking (2024), building upon and extending Markard et al. (2020).

However, so far the discussed policy implications remain at a very high level of abstraction, with little insights on the specific role of regulation in the acceleration phase of transitions. Indeed, more generally speaking, research on the role of regulation for sustainability transitions has been limited, but started to be emphasised (Geels and Gregory, 2023). Such considerations should build on the seminal literature on the Porter hypothesis (Porter and van der Linde, 1995a, b), which suggests that strict environmental regulation triggers 'innovation offsets' resulting in resource productivity and higher economic efficiency. Notwithstanding, the literature has remained ambiguous in the understanding of regulation, with two main literature streams to be distinguished (Fig. 1).

The first stream of research considers regulation nearly as a synonym for policies, which we refer to as *regulation in the broader sense*.

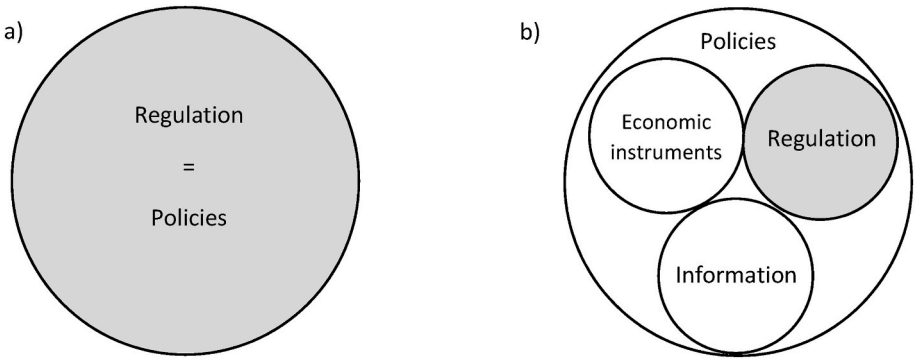

Fig. 1. a) Regulation in the broader sense and b) regulation in the narrower sense.
Source: own elaboration.

According to Braunerhjelm et al. (2023), a common thread among such definitions on regulation refers to political authority enforcing compliance to regulations, as shown by the OECD (2023, 10): "*Regulation is the diverse set of instruments by which governments set requirements on enterprises and citizens. Regulation includes all laws, formal and informal orders, subordinate rules, administrative formalities and rules issued by non-governmental or self-regulatory bodies to whom governments have delegated regulatory powers*." A wide range of tools is considered as regulation, ranging from 'command and control' measures to instruments influencing the incentives and, thus, the behaviour of economic agents. Examples are (quality) standards, price controls, taxes and demand subsidies, disclosure of information or ownership ceilings (Braunerhjelm et al., 2023; OECD, 2023). Only few regulations have the immediate objective of promoting innovation, for example, by ensuring intellectual property rights. Instead, most regulation aims at correcting market failures, optimising social welfare, containing externalities, and reducing transaction costs (Braunerhjelm et al., 2023; Blind, 2023). Indirect pressure to innovate might be created by the need to comply with, for instance, more rigorous environmental requirements (Blind and Münch, 2024; Braunerhjelm et al., 2023).

The second stream of research regards regulation as one type of several policy instruments, i.e. *regulation in the narrower sense* (e.g., Edler et al., 2016; Rogge and Reichardt, 2016; Reichardt and Rogge, 2013; Rennings and Rammer, 2011; IEA, 2024; IRENA, 2012; UNFCCC, 2000). Broadly speaking, this stream contrasts regulation as command and control measures with economic, i.e. market-based, instruments as well as information (Reichardt and Rogge, 2013). Economic instruments encompass, for instance, tax incentives, grants and loans, subsidies or trading systems. Policies targeting information include professional training on new technologies or public information campaigns. By contrast, regulation understood in the narrower sense focuses upon intellectual property rights, technology/performance standards or market designs such as grid access guarantees or priority feed-ins, to name a few examples. The underlying logic can be traced back to research in environmental economics, which refers to the regulatory strategy of "command-and-control" (Baldwin et al., 2012; Baldwin, 1997). Thus, regulation has been specified as *"the direct regulation of an industry or activity by legislation that states what is permitted and what is illegal"* (McManus, 2020). Command-and-control refers to the standards set by the state, which can be imposed by force of law. In addition to standards controlling the quality of services and products or the manner of production, command-and-control regulation can also govern the allocation of products or commodities and the prices charged to consumers (Baldwin et al., 2012). As the electricity market design is a telling example for a command-and-control regulation, we build on this latter stream, i.e. in this paper we understand regulation in the narrower sense.

The few emerging studies that have paid dedicated attention to the role of regulation in transitions have tended to build upon the conceptual approach of regulation in a broader sense. For instance, Blind (2024) uses the OECD definition for examining the role of regulation related to the policy intervention points for sustainability transitions according to Kanger et al. (2020), effectively including any policies, not just regulation. In the context of experimentation, Bauknecht and Kubezcko (2024, 45) analyse the impact of regulatory experiments and real-world labs on the directionality and acceleration of transition processes, including "*not only regulation in a narrow sense, but rather the full range of public policy instruments.*" Other transition studies do not clarify their definition of regulation, leaving their interpretation ambigious. For example, studying the bioeconomy in Germany and the mobility transition in the Netherlands, Edler et al. (2021) consider regulation as contextual system component, but summarise "policy and regulation" as one transformation dimension. Similarly, Feser et al. (2024) conduct a comparative study on the up-take of 27 international regulatory experiments for sustainability transitions, yet do not focus on the regulatory content itself but on the experiments' transferability, scalability, and unintended consequences.

Taken together, we see a lack of conceptual clarity in studies on regulation with one stream of literature referring to regulation as synonymous with policies (regulation in the broader sense) and another stream considering regulation as one sub-set of policy instruments (regulation in the narrower sense). We argue that it is important to differentiate both streams, and that future research needs to advance both our understanding of policy in general for accelerating transitions, but also and even more so of regulation in particular. Therefore, we suggest to use policy as overarching term, whereas studies focusing on regulation – in the narrower sense – should unpack the specific instrument type and its relative role in accelerating transitions (see Fig. 1 b). In doing so, we agree with Blind (2024, 11), who calls for more regulation-related research on the *"agency of the involved actors […] driven by their interests and enabled by their means"*. In this vein, we now elaborate on our conceptual consideration for analysing the regulatory capacity of state actors for inducing regulatory changes in accelerating net-zero transitions.

2.2. Capacities and capabilities for governing transitions

There is a wide scholarship on the governance of transitions (Köhler et al., 2019; Frantzeskaki et al., 2012), with transition scholars increasingly acknowledging the relevance of the state for governing sustainability transitions (Johnstone and Newell, 2018). Recent contributions particularly concern the organisational level of state actors, using different terms and emphases, e.g., regarding roles and tasks (for an overview, see Appendix A). For example, Borrás and Edler (2020) identify various embedded roles of the *'state'* depending on distinct modes of governance in socio-technical systems. Relatedly, Braams et al. (2021) compare the transition tasks of '*governments'* with the normative arguments of the Public Administration traditions for legitimising

government action. Braams et al. (2022, 2023) focus on *'civil servants'* in the Dutch ministry for infrastructure and water, analysing their perception on their legitimacy and tactics for realising transition tasks. In addition, Borrás et al. (2024) propose a conceptual framework capturing the 'transformative capacity' of *'public sector organisations'* for changing institutions consisting of roles, resources, and abilities. While studying the dynamic interactions of Chinese *'governing entities'* in designing the policy mix for electric vehicles, Song et al. (2023, 3) refer to entities '*in charge of the design, implementation, and governance of the focal policy mix*'. For our purposes of investigating regulating and legislating entities relevant for regulatory change, we consider *'governing entities'* as most appropriate term – it is not too broad such as 'the state' or any 'public sector organisations' nor too narrow such as 'civil servants'.

As regards the capacity of state actors, the literature on sustainability transitions focuses on various dimensions and scales, often on a systemic (national) level (e.g., La Belle, 2017; Konrad et al., 2021) or an urban scale (e.g., Wolfram, 2016; Hölscher, 2020). Concerning the organisational level, some contributions focus on '*green dynamic capabilities*', particularly of governmental organisations for creating and implementing green innovations (Arshad et al., 2023; Van Welie et al., 2019). With respect to the acceleration phase, Rogge and Song (2025) investigate transformative policy capacities for accelerating transitions by taking acceleration challenges and policy mix intervention points into consideration. Based on a review of the literature on public governance and public administration studies, innovation studies and sustainability transitions, Borrás et al. (2024) conceptualise the transformative capacity of public sector organisations as interaction of the three core constitutive elements roles, resources and abilities. We adopt this arrangement of roles, resources and abilities, since we consider the interaction of these three elements valuable for analysing the capacity of governing entities needed in the acceleration phase.

As first element, roles of state actors mean the variety of purposeful tasks when enacting institutional work during transitions. Acknowledging the purposeful character of these roles, Borrás et al. (2024) follow the guidance provided by the literature on institutional work and, thus, distinguish roles, which aim at creating, maintaining and disrupting institutions towards system change (Lawrence and Suddaby, 2006).

Resources are defined by Borrás et al. (2024) as the set of internal or external material or immaterial assets that that can be mobilised by state actors to enact their transformative roles. They differentiate between human, physical, financial, legitimacy, network and cultural resources, as well as political mandates and data and information. By human resources, for instance, they mean staff and man power. Legitimacy resources relate to reputation, social acceptance and authority as well as trustworthiness. Political mandates mean the legal and regulatory status. By means of network resources, they refer to contacts, access to decision making, relational and inter-organisational resources. Cutural resources encompass public administration and bureaucratic culture or the general organisational culture in the society.

Abilities are the routines, practices, and procedures inside the organisation when exercising transformative agency (Table 2). Borrás et al. (2024) cluster these abilities into four categories: analytical, operational, coordination, as well as learning and reflection. We complement this by political capacities, for which we draw on Wu et al. (2015). Therewith, we respond to Rogge and Song (2025), who call for more research on organisations' political capacities for accelerating transitions, since governing entities will be key in navigating the 'dual politics' of transitions (Rogge and Goedeking, 2024): overcoming political pressures from powerful, established regime actors and reaching political trade-offs between different groups of actors, especially across different socio-technical systems, for building the new regime (see also Avelino and Wittmayer, 2016; Stirling, 2014). Thus, we further take account of context-specific conditions (Roberts and Geels, 2019; Roberts et al., 2018), as we expect political skills to be critical in the German context. For this, recent contributions emphasise political contestation and the resistance of automotive incumbency related to transport electrification policy (Meckling and Nahm, 2018; Rogge and Goedeking, 2024) and regulation (Käsbohrer et al., 2024).

Table 2
Abilities for transformative capacity in the acceleration phase.

Type of abilities	Explanation
Analytical abilities	Exploring, studying, and interpreting and, more concretely, mobilising original and relevant new knowledge, to advice for public action, to develop new ideas and visions, also including new forms of public innovation, futuring and anticipatory skills in various forms, future-scenario building, simulation models, or similar anticipatory tools as well as the ability to develop imaginaries in relation to socio-technical transformations.
Operational abilities	Managerial and administrative abilities to put in place the practical operation needed for transformative action, such as, securing legal enforcement, administrative or managerial skills as well as effective reporting, monitoring, verification, and sanction mechanisms.
Coordination abilities	Ability to develop and engage in inter-organisational collaboration with other public organisations across government levels, and to participate in governance networks or social innovation networks.
Learning and reflexivity abilities	Ability to develop and incorporate new understandings and adjust its own action accordingly, by means of adaptation and re-consideration.
Political abilities	Dealing with political judgements, cross-actor negotiations or trade-offs and the establishment of new governance structures encompassing, for instance, communication with stakeholders and the general public, stimulating and orchestrating multi-stakeholder participation, communication and engagement, negotiations and consensus building.

Source: Own compilation based on Borrás et al. (2024) and Wu et al. (2015).

2.3. Analytical framework for investigating the interplay between regulation and acceleration transitions

To address the identified shortcomings in both literature streams, we develop an interdisciplinary analytical framework that bridges the gap between the literatures on acceleration challenges and on state capacities for governing transitions, with a dedicated focus on regulation as one type of policies. Our framework consists of the following two major building blocks: first, acceleration challenges with their regulatory implications, and second, regulatory state capacity enabling regulatory change needed to tackle these acceleration challenges, thereby paving the way for speeding up net-zero transitions. More specifically, and as schematically displayed in Fig. 2, we thus identify regulatory implications, which result from challenges unique to the acceleration phase of transitions (left part of our framework). Here, we focus on regulation in the narrow sense, thereby emphasising the specific relevance of regulation in the acceleration phase (see section 2.1). Simultaneously, we detect what kind of state capacity is necessary for responding to these challenges through regulatory change, thereby aiming for accelerating transitions (right part of our framework). As outlined in section 2.2, this regulatory state capacity is operationalised by means of roles, abilities and resources.

3. Research design

In order to gather in-depth insights on the agency of governing entities on an organisational level, we conduct a qualitative case study (Yin, 2014). In the following, we first provide an overview of the selected case, before describing data collection and analysis.

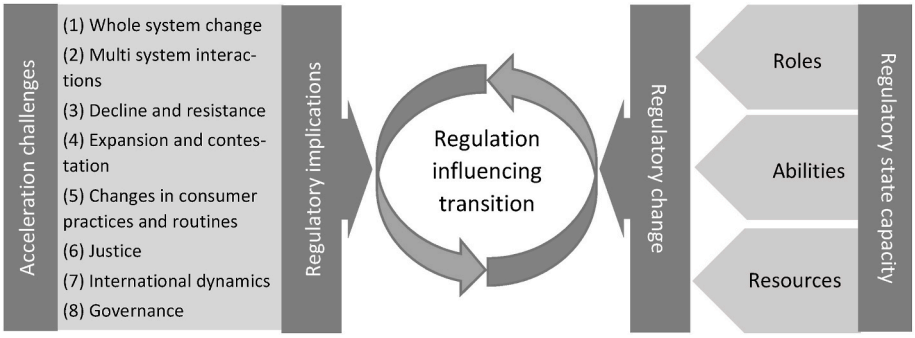

Fig. 2. Analytical framework for investigating the role of regulation in accelerating transitions.
Source: own elaboration.

3.1. Case selection

Our research case covers electricity storage in general, and residential storage in particular. In this regard, the initially most common use case of residential storage systems (up to 30 kWh) was "prosuming" (a terminological hybrid of *pro*ducer and con*sumer*), which aims at enhancing self-production and self-consumption of solar electricity in private households by storing surplus electricity beyond current consumption (Fig. 3; Tepe et al., 2021; Kairies et al., 2019). Since then, further business models have been developed. Residential storage is part of private energy management systems (smart homes), which facilitate demand side flexibility by connecting electrical loads (storages, heat pumps, electric vehicles, etc.) and producers (typically photovoltaics). These behind-the-meter systems (which means that electricity is used without passing through a meter) have been complemented by more system-relevant front-of-the-meter applications providing electricity to locations beyond the private home, for example, feeding the grid. More specifically, large numbers of digitally aggregated photovoltaic and storage systems (so-called virtual power plants) can provide a frequency containment reserve in order to balance variation of mains voltage through storing or withdrawing electricity during times of interruption or overproduction (Becker et al., 2024; Sousa et al., 2019). Moreover, such virtual power plants can take advantage of price volatility in international electricity trade through timed sales. Another potential use case are so-called "energy communities" organised by a third party aggregator (so-called energy sharing), enabling members to sell and buy electricity from other peers depending on their current demand or surplus production (Blasch et al., 2021; Mlinarič et al., 2019).

Against the backdrop of these developments, several aspects substantiate our case: First, given the necessity of storing electricity generated with renewables, the technology by itself constitutes a necessary complementary interaction for whole system change, which becomes crucial to tackle in the acceleration phase of net-zero transitions (Markard et al., 2020; Markard and Hoffmann, 2016). Moreover, residential storage systems contribute to a changing system architecture by facilitating decentral self-generation and self-consumption in private households (Wieczorek et al., 2024; Andersen et al., 2023b). Not least, we observe an increasing integration with other systems, such as mobility and heating, with such multi-system interactions being another characteristic for accelerating net-zero transitions (Andersen et al., 2023a; Löhr and Chlebna, 2023; Mäkitie et al., 2022; Rosenbloom, 2019).

We argue that Germany constitutes a telling example for investigating the regulatory implications arising from the challenges occurring in the acceleration phase of net-zero energy transitions and the regulatory state capacities for regulatory change. First, Germany has advanced significantly in its transition away from fossil fuels and nuclear energy towards renewables, as evidenced by a rapid expansion of installed PV capacity. This is connected to high dynamics in the market for residential storages systems as well as e-mobility (Fig. 4). Second, the

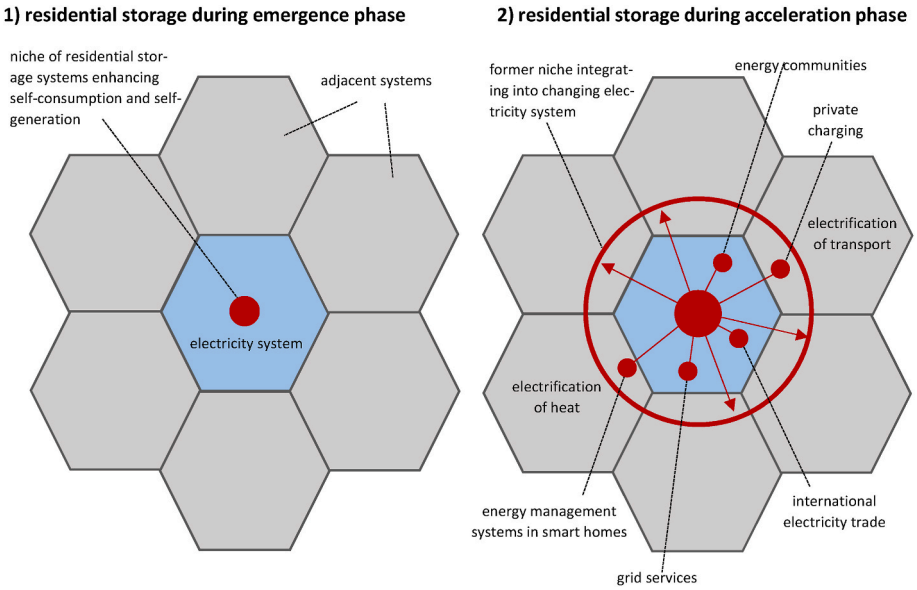

Fig. 3. Positioning the residential storage system in the transitioning electricity system: 1) during emergence phase, 2) during the acceleration phase.
Source: Own elaboration based on Markard et al. (2020).

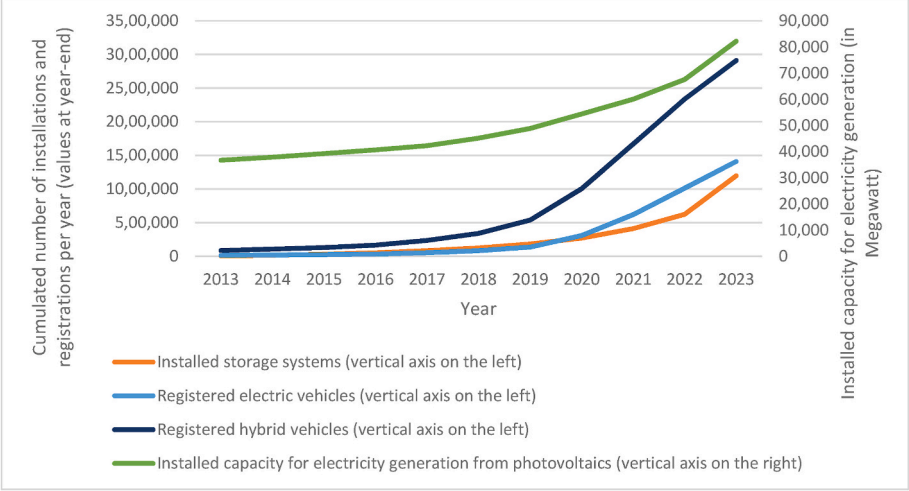

Fig. 4. Installed capacity for electricity generation from photovoltaics (in Megawatt), cumulated installation figures of stationary residential storage systems (up to 30 kWh) and stock of licensed passenger cars with electric or hybrid engines for the years 2013 until 2021 in Germany, estimated and rounded values at years-end. Source: Own illustration based on Bundesverband Solarwirtschaft e.V. (2024); Kraftfahrt-Bundesamt (2024, 2023); Umweltbundesamt (2024).

market for residential storage systems in Germany was the largest in Europe in absolute terms as well as relative to population in 2022 (ees Europe, 2023). This market for residential storage systems dates back to the first decade of the new millennium, with a significant take-off in the years 2013 and 2014. Finally, advocates of residential storage systems (e.g., industry associations, storage manufacturers and electricity providers) regard regulation in Germany as key obstacle to a more profitable realisation of business models involving storage systems beyond self-consumption due to, for instance, fees and charges or complex metering requirements (Käsbohrer et al., 2024; Zademach and Käsbohrer, 2022). Thus, the German case is very suitable for analysing the required alignment of regulation in response to the challenges arising in the accelerating phase of net-zero transitions.

3.2. Data collection and analysis

Empirically, we conduct a case study on residential storages, drawing on two data sources: expert interviews and participant observation. Our qualitative analysis is primarily based on the insights gained through our semi-structured expert interviews (covering business, governing entities, research etc.) conducted in two phases between February 2021 and September 2024 and yielding a total of 39 interviews with close to 2400 min of interview material (see Table 3). This interview data was enriched by participant observation in industry association meetings, which included 45-min to day-long events and provided valuable context information on regulatory amendments and industry stakeholders' reactions (See Appendix B).[1]

The scoping phase (between September 2020 and April 2023, 31 interviews) allowed us to understand the technology and associated business models as well as to identify relevant regulatory barriers hampering a further diffusion of residential storage systems. During this first scoping phase, the research focused on institutional work carried out by actors of the electricity and automotive sector (Käsbohrer et al., 2024).

In our deep dive phase (between May 2023 and September 2024, 8 interviews), we asked interviewees about specific challenges emerging in the acceleration phase. We were guided by the acceleration challenges identified in the literature, but also open to case-specific nuances in a more inductive manner. As regards roles, we asked interviewees about their perceived roles in aligning regulation without sticking solely to theory-led categories. In a similar vein, further questions targeted interviewees' perception about lacking and existing abilities and resources as well as their relevance for tackling acceleration challenges by adapting regulation.

The interview transcripts and notes taken during the participant observation were coded in MaxQDA to perform a qualitative content analysis. The coding scheme was informed by the analytical framework, but also enriched through insights from the empirical material (Siggelkow, 2007; Mayring and Fenzl, 2019, for the coding scheme and number of coded text passages see Appendix C, for exemplary quotes see Appendix D). First, we coded the material according to all acceleration challenges, as derived from the literature, but with special focus on regulatory implications. Second, we conducted a bottom-up coding of the regulatory state capacities for coping with these challenges (both

Table 3
Interviews in scoping and deep dive phase.

Scoping phase: February 2021–April 2023		
31 Interviews with experts from: industry associations (6), storages manufacturers (3), electricity providers (3), companies focusing on energy managements systems (2), automotive supplier representative (1), DSOs (2), TSO (1), lawyers (2), researchers (2), research institute (2), Chamber of Commerce and Industry (1), State Network Agencies (2), Federal Network Agency BNetzA (1), Ministry for Economic Affairs and Climate Action BMWK (1)		
Deep dive phase: May 2023 - September 2024	**Date**	**Duration**
Industry association representative (energy sector)	May 2023	69 min.
Ministry for Economic Affairs and Climate Action (BMWK): Civil servant	Nov 2023	70 min.
Ministry for Economic Affairs and Climate Action (BMWK): Civil servant	May 2024	20 min.
Industry association executive director (energy sector)	May 2024	67 min.
Ministry for Economic Affairs and Climate Action (BMWK): Civil servant	June 2024	38 min.
Federal advisory authority in the field of charging infrastructure	June 2024	45 min.
State Network Agency representative	Aug 2024	37 min.
Federal Network Agency representative (BNetzA)	Sept 2024	72 min.

[1] Three interviews during the scoping phase were conducted by the first and third author, while the remainder of the interviews were solely conducted by the first author. Four interviews are follow-up interviews with an interviewee who was interviewed for the second time. The participant observation was carried out by the first author.

required and missing). During the coding process, we applied the change in government as analytical lense with the purpose of unveiling if concomitant changes in state capacities resulted in regulatory changes. In order to increase the validity of our findings, we cross-validated statements of interviewees amongst each other, including among different experts affiliated to the same organisation or department.

4. Findings

We start the findings section by elaborating on the institutional context of energy regulation in Germany (in section 4.1), before moving on to the challenges and regulatory implications slowing down the diffusion of residential storage systems (in section 4.2). Regarding regulatory state capacities for tackling these challenges, our analysis reveals two main phases, which differ in the focus of institutional work: maintaining (in section 4.3) and creating (in section 4.4). We conclude the findings section with a synopsis table (in section 4.5).

4.1. Institutional context: German energy regulation

The Renewable Energy Sources Act (*Erneuerbare-Energien-Gesetz, EEG*) and the Energy Industry Act (*Energiewirtschaftsgesetz, EnWG*) set the market design of the German electricity system including the promotion of renewable energies. As the primary legislation regulating the German electricity market, the EEG and EnWG define market roles in the electricity system (production, consumption, transport), differentiate between types of electricity (conventional and green), set measurement requirements, declare exemptions of grid fees, taxes, and surcharges, and regulate grid access for electrical loads, such as storage systems.

As regards amending the central legislation, formal decision-making power lies with the German federal parliament. The substantive work on the legislation is mainly the responsibility of the Ministry of Economic Affairs and Climate Action (BMWK). The Federal Network Agency for Electricity, Gas, Telecommunications, Post and Railway (BNetzA) serves as downstream executive authority, mandated with guaranteeing the liberalisation and deregulation of the electricity market via non-discriminatory network access and efficient system charges (Bundesnetzagentur, 2024). Associated with a high level of expertise and commitment, BNetzA representatives are involved in amendments of EEG and EnWG in close collaboration with the BMWK. Thus, we focus on these two governing entities when unpacking regulatory changes and the associated state capacities.

4.2. Acceleration challenges and regulatory implications: residential storages in the German electricity system

The accelerated diffusion of residential storage systems in Germany faces four main obstacles, which can be traced back to various interacting acceleration challenges.

First, in order to avoid critical grid conditions through storing electricity, a better system integration through front-of-the-meter services is needed [1-WHO]. This refers to the controllability of photovoltaics and residential storage systems and to the sale of surplus electricity on the electricity exchange according to price signals through a third-party marketer ('Direktvermarktung') in order to prevent photovoltaics from feeding in maximum electricity at midday and to facilitate the feeding in of electricity into the grid in times of low grid voltage. However, our empirical material suggests that only a small part of residential storage systems works in a system-integrating manner beyond mere behind-the-meter storing of self-produced electricity for a later usage. Being further electrical loads, electric vehicles and heat pumps reinforce this issue, but also enhance the potential of storage systems in mitigating critical grid conditions, due to a several times higher storage capacity [2-MSI]. The main reasons for this missing system integration are linked to system governance [8-GOV] and its implications: the delayed rollout of smart-meter-gateways, the missing digitalisation of low-voltage grids and the mandatory separation of green and conventional grid power leading to complex metering requirements since the different electricity flows are associated with different subsidies, taxes and fees respectively (§ 19 EEG).

Second, the amendments of the EEG and EnWG are highly contested [4-EXP]. Interviewees mention industry associations, consumer organisations, industry stakeholders from the electricity and (increasingly) mobility system, and parliamentarians as main contestants. Whereas the legal environment of EEG and EnWG allows for an enhanced self-consumption share through storage, contestation revolves around a number of issues. First, the above-mentioned compulsory separation of conventional and green electricity hinders grid services (frequency containment reserve). Second, introducing a legally binding definition of storing electricity would exempt storages from grid fees and surcharges. Third, the introduction of industry standards is often contested, too, as they can influence future business models or market success. For instance, communication interfaces for public charging determine who is in a better position to handle the payment process. Fourth, tax and surcharge burdens still hamper energy communities including energy sharing. Fifth, regulation on bidirectional charging including grid charging periods of private electric vehicles, which also affects residential storage systems (§ 14a EnWG), is missing. In this context, justice-related concerns are reflected in regulation, as interviewees of regulatory agencies highlight a fair distribution of fees and charges as well as costs for grid expansion, also including owners of residential storages [6-JUS]. Furthermore, multi-system interactions reinforce this contestation, since the automotive industry is intensifying their advocacy work towards BMWK and BNetzA, such as regarding the grid-oriented controllability of storages and electric vehicles. For example, in 2021, after an intervention of an automotive industry association, a draft law (§ 14a EnWG) was cancelled, which would have authorised DSOs to control charging periods of private electric vehicles and residential storage systems and, thus, would have prevented customers from flexibly connecting their appliances to the grid [2-MSI]. Against this backdrop, industry stakeholders and representatives of regulatory agencies note that the accommodation of particular interests is one reason for the high complexity of German energy regulation and potentially delayed regulatory changes [3-DEC].

Third, industry stakeholders allege EU legislation, which fosters the self-consumption of electricity and energy sharing, and which needs to be transposed into member states' regulation [8-GOV]. While industry stakeholders emphasise a lack of implementation of EU legislation (e.g., reliefs for fees and charges particularly for energy communities, reducing bureaucracy and metering requirements), BMWK and BNetzA representatives point to ambiguities and vagueness with respect to residential storages in EU legislation (e.g., regarding grid fees, definition of storages). Futhermore, they criticise in particular industry associations for not clearly outlining inconsistencies [4-EXP].

Fourth, industry experts criticise governing entities, in particular the BNetzA, for not having acknowledged the emotional motivation of consumers for a long time. According to almost all interviewees, emotional aspects like a fascination for the technology or enhancing a user's degree of autarky with self-produced electricity motivates consumers to buy storages, electric vehicles, and heat pumps. Notwithstanding, when it comes to behavioural change, an industry association representative and a BNetzA representative emphasised the importance of an appropriate pace of change, as too far-reaching obligations or too many amendments are likely to trigger a rather defensive attitude of future consumers [5-CON].

4.3. First period: institutional work focusing on 'maintaining'

Especially under the last Merkel government, industry stakeholders have criticised the regulatory environment for obstructing a more profitable realisation of business models involving residential storages and rather maintaining a status-quo.

From a whole-system perspective [1-WHO], our empirical material reveals an often critical attitude towards residential storage systems in BMWK and BNetzA *[cultural resources]*. In 2021, a BMWK representative stated that opinions on the potential of residential storage systems vary very strongly across BMWK employees. Thereby, the arguments against storage systems are usually of a technocratic nature. For instance, in 2021, a BNetzA representative emphasised that residential storages hamper households' predictability and controllability. Furthermore, the interviewee questioned their need and profitability and rather pleaded in favour of a full feed-in of self-produced electricity, drawing on the arguments of following market signals in an efficient way and of a true-cost pricing of net electricity with grid fees, since electricity has to be fully available at any time in spite of residential storage systems [3-DEC]. In this context, representatives of both entities emphasise the need to *warn* of and *mitigate* the potentially negative effects of storages for end consumer in terms of fees and charges [6-JUS].

As regards the above mentioned resistance [3-DEC] and contestations [4-EXP], the roles of *moderator* and *gatekeeper* along with *political abilities and human resources* are highly relevant for handling divergent interests and advocacy work including public (associations') hearings, the publication of (draft) legislation, and the incorporation of feedback of industry stakeholders (e.g., position papers). In *operational* terms, industry stakeholders emphasise too short deadlines, for example for associations to write position papers regarding draft legislation. Representatives of BMWK and BNetzA admit this problem and argue with their workload. By contrast, BMWK and BnetzA interviewees highlight the challenge of having sufficient *knowledge* and *analytical abilities* for aligning regulation to emerging business models given their perception of an insufficient clarification of business models and regulatory barriers by industry experts and particularly industry associations.

Concerning the implementation of EU legislation [8-GOV], *moderators* are needed for both vertical and horizontal *coordination*. This includes communicating national interests in consultation with the Federal Government towards the EU level *[vertical coordination]*. Furthermore, a BMWK representative highlights the challenge of examining very detailed EU legislation and identifying potential inconsistencies with national regulation, which requires *analytical abilities, knowledge* and *human resources*. Similarly, consensus-building across ministries and departments and a non-compartmentalised *horizontal coordination* of regulation is necessary, since emerging use cases including public and private charging have to be aligned with basic principles of energy regulation (separation of electricity flows). Furthermore, transnationally valid cross-system elements, like communication interfaces and smart-meter gateways, need to be standardised. In this context, representatives of BMWK and BNetzA highlight the close collaboration between both entities, but mention difficulties regarding, for instance, the Federal Ministry for the Environment. Furthermore, interviewees from both the industry side and of regulatory agencies attribute the delayed rollout of smart-meter gateways to *coordination* failures between BMWK and the Federal Office for Information Security involved in the standardisation process.

The amendments of EEG and EnWG in 2021 showed changes, however, mainly complying with the requirements of EU legislation and rather small-scale, incremental in nature (see Table 4).

Table 4
Main regulatory changes through amendments of EEG and EnWG affecting the market for residential storage systems in Germany.

Main regulatory changes affecting residential storage systems under the Merkel government 2018–2021 (with Peter Altmeier from the CDU as economics minister)[a]	
EEG 2021	- Easier grid access for storage systems (§8 Abs. 5 S. 3 EEG). - Threshold for exemptions of grid fees, taxes and surcharges set from 10 kWh to 30 kWh for new and existing installations (§ 61 Abs. 1 EEG) (as required by EU regulation), thus, avoiding de-facto double charging with grid fees, taxes and (EEG-) surcharges for installations <30 kWh in the course of storing and withdrawing electricity from the storage (grid services) due to high and complex measurement requirements (§§ 60, 61l EEG). - § 61l EEG simplified, grid services involving storing and withdrawing electricity from the storage possible for prosumers without double charging with taxes and (EEG-) surcharges. (*However, not applied to grid fees and still highly complex in terms of measurement requirements).* - Joint production and usage of renewables by self-consumers located in the same building (landlord-to-tenant electricity) facilitated, as electricity can be delivered by a third party instead of the facility operator itself (§ 21 Abs. 3 EEG). Furthermore, higher government subsidies for projects in rental apartments (§ 48 EEG).
EnWG 2021	- Fees and charges (§ 19 Abs. 2 EnWG, § 17f Abs. 5 EnWG 'offshore grid fee' § 48 EnWG 'concession fee') measured analogously to § 61l EEG. (*However, not applied to grid fees §*118 Abs.6 EnWG*).*

Source: Erneuerbare-Energien-Gesetz (EEG) in Clearingstelle (2025b); Energiewirtschaftsgesetz (EnWG) in Clearingstelle (2025c).

[a] The full name of the economics ministry at this time was Bundesministerium für Wirtschaft und Energie (Federal Ministry of Economic Affairs and Energy, BMWi) – for simplicity, we refer to it as BMWK in the text. The EEG amendment came into force in January 2021, the EnWG amendment in July 2021.

4.4. Second period: institutional work shifting to a focus on 'creating'

The introduction of the new Scholz government[2] in the end of 2021 marks a change in the institutional work carried out by BMWK and BNetzA towards creating the new rules of the game. The government's aim of expanding residential photovoltaics triggers the will to integrate electrical loads into the electricity system in a grid-friendly manner for avoiding critical grid conditions. Thus, the grid-friendly system integration is almost unanimously recognised on the agenda in both institutions *[learning*, 1-WHO].

As regards whole system change [1-WHO], BMWK representatives describe their role as *facilitating* and *promoting* the expansion of photovoltaics and residential storages by using their *mandate resources* to increase the photovoltaic expansion path and removing regulatory barriers for the system integration of all storage types (residential, mobile, large scale, pumped storage hydro power stations). Thereby, BMWK representatives emphasise the aim of a viable overall system optimum, level playing fields for the different storage technologies in terms of fees and charges [6-JUS] and reducing the high complexity of German energy regulation. In this context, they emphasise the need to avoid the accommodation of particular interests such as unjust privileges regarding fees and charges or unfair standards, which requires *knowledge and human resources* as well as *analytical abilities* [3-DEC].

The BNetzA has been *observing* the critical grid conditions associated with the midday peak of photovoltaics and *warning* of potential blackouts. In this context, in 2024, a BNetzA representative (the same expert that has been interviewed in 2021 already) stated that the potential of front-of-the-meter business models involving residential storages, electric vehicles, and heat pumps for flexibilising electrical load and generation and containing these critical grid conditions has been underestimated for a long time *[learning and reflexivity]*. Hence, while in charge of the detailed technical design of metering requirements and grid fees, the BNetzA has started to work on a less stringent model for metering green and conventional power for *mitigating* this problem *[cultural resources]*. In this context, the BNetzA representative further points to challenges in communicating draft regulation and amendments towards industry experts, politics and the public, given a declining legitimacy after various already conducted amendments *[legitimacy resources;* 5-CON].

As regards multi-system interactions [2-MSI], a new BMWK department for the system integration of electric vehicles, heat pumps and storage systems, a consulting agency on e-mobility and charging (NOW GmbH), and new meeting formats, such as working groups between

[2] The Scholz government with its so called 'traffic light' coalition between Social Democrats (SPD), Greens (Bündnis 90/Grüne) and Liberal Democrats (FDP) began government work in December 2021.

economics and transport ministries (BMWK and BMDV), have been initiated *[coordination and operational abilities]*. Moreover, new BMWK employees experienced in this field were hired in the wake of the change of government *[human and network resources]*. Thus, there has been an increase in *knowledge and analytical abilities* on interface aspects, such as bidirectional charging *[learning]*. However, industry stakeholders criticise the to some extent still prevailing reluctance and silo mentality separating, for instance, electricity and mobility related issues, instead of defining overall visions and guidance (also in the sense of educating the public) towards a broad reconceptualisation of the electricity market including cross-system regulation *[cultural resources;* 5-CON*]*.

Regarding concrete regulatory changes, BMWK and BNetzA interviewees and further industry stakeholders emphasise that far-reaching regulatory changes have been advocated by the new government, in particular by the FDP's parliamentary group (see Table 5). Flexible electricity tariffs, the above-mentioned separation of green and conventional electricity as well as enabling energy communities are topics that are currently being worked on.

4.5. Synopsis of findings

Table 6 provides an overview of our findings on the required regulatory state capacity (on the right) arising from the regulatory implications of the acceleration challenges (on the left) in Germany's energy transition. In the table, we focus on unpacking the roles, abilities and resources needed for tackling regulatory change meant to address the various types of acceleration challenges.

5. Discussion

5.1. Interplay of regulatory implications of acceleration challenges and required regulatory state capacity

Given our focus on regulation as one specific type of policies, we were able to derive four overarching regulatory implications resulting from acceleration challenges, thereby deepening existing insights on general policy implications arising from such challenges in the acceleration phase of net-zero transitions (see Table 1 in section 2.1).

First, our case reveals that major regulatory change is required but hindered by a high degree of *institutionalisation*. Indeed, regulation sets the basic, overarching rules of the game, which in our case constitute the electricity market design. Against this backdrop, we find that unfolding 'whole system change' is one of the key acceleration challenges affecting regulation and regulators. More specifically, storage systems – mainly used for storing self-generated electricity for later use – need to be integrated into the electricity market design in a grid-oriented way. Thereby, basic principles are affected and need to be adapted (e.g., metrological separation of electricity flows, grid fees and charges). In this context, introducing new technologies or new legal roles, like the storing of electricity, constitutes a major endeavour, since these basic principles and rules are highly institutionalised, and also shaped by exemptions and particular privileges. Given the associated politics of accelerating transitions resulting from path dependencies and resistance from vested interests, which is also referred to as "capture" in regulation theory (Breyer, 1982), we find initially rather incremental updates instead of major reforms, which, however, would be necessary for accelerating net-zero transitions. Such major electricity market reform is a key role for regulators, and requires not only high analytical but also strong political abilities.

Table 5
Main regulatory changes through amendments of EEG and EnWG affecting the market for residential storage sys-tems in Germany under the Scholz government (2021–2025).

Main regulatory changes affecting residential storage systems under the Scholz government 2021–2025 (with Robert Habeck from the Greens as economics minister)[a]	
EEG 2023	- Suspension of EEG surcharge (§ 58 EEG). - Significant increase in the annual expansion path of solar PV. - Simplified measurement at grid connection point (behind-the-meter): most fees and taxes only relate to withdrawals from and feed-ins of electricity to the grid, balancing of electricity flows (acc. to §21 EnFG 'Energiefinanzierungsgesetz', former § 61l EEG). (*However, still contested: grid fees and electricity taxes in multi-use applications).* - Storage losses are exempt from charges and fees (§ 21 EnFG). - New rates of feed-in compensations for prosumers completely and partly feeding in (involving self-consumption) with the latter being reasonably high and, thus, enhancing the installation of a storage system in addition to photovoltaics (§ 100 Abs. 4 EEG).
EnWG 2023	- New definition of 'storage' as new category besides generation, transport and consumption (§3 Abs.15d EnWG).

Source: Erneuerbare-Energien-Gesetz (EEG) in Bundesministerium der Justiz (2023b) and Clearingstelle (2025a); Energiewirtschaftsgesetz (EnWG) in Bundesministerium der Justiz (2023a) and Clearingstelle (2025d).

[a] The full name of the economics ministry at this time was Federal Ministry of Economic Affairs and Climate Action (BMWK). The EEG amendment came into force in January 2023, the EnWG amendment in December 2023.

Second, what complicates things further is that these long lasting, highly institutionalised rules governing the electricity market are characterised by high and ever increasing *complexity*. As proposed by Baldwin et al. (2012), infrequent revisions and the failure to prune regulations has led to an ever-denser thicket of rules. Our interviewees – both industry experts and regulators – confirm the high complexity of the German electricity market design, which poses regulators with the challenge of ensuring consistency in the regulatory mix as part of the wider policy mix. For instance, our empirical material revealed inconsistencies between the EEG and the regulation for measuring point operation. Avoiding such inconsistences requires a high level of human and knowledge resources as well as enhanced analytical and coordination abilities.

Third, we find a high degree of *contestation* around setting the new rules of the game for expanding the net-zero trajectory, which regulators must navigate. As already suggested by Rogge and Goedeking (2024) in the context of the electrification of transport, this acceleration challenge of 'expansion and contestation' plays a critical role in our case of residential storage, too, and also interacts with other challenge types, in particular 'governance', 'justice' and 'multi-system interactions'. Advocacy work revolves around the argument of Germany not having implemented EU legislation, which demands exemptions from fees and charges for electricity storage solutions. In response, regulators point to inconsistent EU legislation. In addition, regulators consider ensuring 'justice' as their duty and, thus, argue with just fees and charges for every electrical load connected to the grid. Furthermore, the increasing advocacy work carried out by stakeholders belonging to the mobility system requires regulators to expand their knowledge resources and analytical abilities to the new reality of 'multi-system interactions'. Examples are the contestation around the controllability of electrical loads such as electric vehicles and storage systems or standards and communication interfaces regulating payment transactions for vehicle charging. Taken together, the crosscutting nature of contestations in the expanding trajectory reinforces the relevance of political abilities as important aspect of regulatory state capacity.

Fourth, our case highlights the *accelerating effect of multi-system interactions*. The scholarship on multi-system interactions suggests that complementary technologies can accelerate transitions, due to, for instance, alignments in institutional work carried out by actors from multiple system or cross-system user learning (e.g., Andersen and Geels, 2023; Rosenbloom, 2019). Our results suggest that this also holds true for the governance dimension, as electric mobility reinforces the awareness of critical grid conditions within governing entities and enhances the potential of business models including residential storage systems and electric vehicles in mitigating this issue. However, designing multi-system regulation, which takes advantage of the potential of multi-system business models, requires greater non-compartmentalised coordination as part of regulatory state capacity.

Table 6
Challenge-specific regulatory implications in accelerating net-zero transitions and required roles, abilities and resources for coping with these challenges.

Acceleration challenge	Regulatory implications	Required regulatory state capacity
(1) Whole system change	1. Aligning regulation with whole system change instead of integrating single innovations in existing regulatory frameworks: Introducing new system roles/elements (storages as system element), regulation of infrastructure, standards (e.g., communication interfaces, charging infrastructure, smart-meter) 2. Defining and facilitating a viable overall system optimum instead of individual optimum (grid-friendly integration of residential storages) 3. Avoidance of regulatory complexity and inconsistencies (e.g., regulation on metrology) 4. Level playing field for different technologies (e.g., in terms of fees and charges, and grid connection requests)	**Roles: facilitator, promotor, warner, observer, mitigator** **Abilities: analytical** (understanding up-to-date developments regarding markets, technologies, business models etc. as well as interplay of elements), **learning and reflexivity** (understanding and re-evaluating potential of storage systems) **Resources: human** (man power for designing regulation), **knowledge** (regarding markets, technologies), **network** (non-compartmentalised working culture), **cultural** (critical attitutude, less stringent metering requirements), **mandate** ('license' to increase the photovoltaic expansion path)
(2) Multi-system interactions	1. Non-compartmentalised, integral regulatory changes (e.g., grid integration of interface business models) 2. Handling institutional work from new systems (e.g, advocacy stemming from the automotive system) 3. Fair market conditions for all systems involved (e.g., avoiding accommodating particular interests) 4. Standardisation of cross-system elements (e.g., metering requirements and smart meter for residential and mobile storages; communication interfaces)	**Roles: moderator, gate keeper** **Abilities: Political** (handling advocacy work of actors associated with different systems), **analytical and learning** (understanding of cross-system technologies, business models, standards etc.), **coordination** (better inter-organisational collaboration), **operational** (new entities at the interface of systems, harmonising cross-system technologies and standards, e.g., smart-meter) **Resources: knowledge** (on multi-system interactions), **network** (new interaction formats), **human** (time consuming interaction with new stakeholders from different systems), **cultural** (visionary thinking, overcoming silo mentality)
(3) Decline and resistance	1. Support structural change by phasing out regulation (e.g., suspension of EEG-surcharge) 2. Abolishing former particular privileges (e.g., regarding fees and charges)	**Roles: facilitator** **Abilities: political** (moderating incumbent interests, overcoming contestation), **learning** (reevaluating technologies and business models); **analytical** (advocacy work, such as position papers, needs to be analyzed regarding particular interests **Resources: Human** (handling advocacy work); **knowledge** (for identifying particular interests); **cultural** (critical attitutude, less stringent metering requirements)
(4) Expansion and contestation	1. Moderating regulatory changes in the context of vested interests and political contestation stemming from different stakeholders (e.g., contestation around fees, charges, taxes, data access, product and green finance standards), avoiding the accommodation of particular interests 2. Handling internal contestation around technological trajectories (e.g., heterogeneous attitudes towards different storage technologies)	**Roles: moderator, gate keeper** **Abilities: Analytical** (for aligning regulation to emerging business models; advocacy work, such as position papers, needs to be analyzed regarding particular interests); **Political** (handling advocacy work of different stakeholders, communicating draft amendments); **Operational** (processes enabling stakeholder involvement such as appropriate deadlines) **Resources: Human** (handling advocacy work), **knowledge** (on business models and interests), **legitimacy** (communicating regulation and amendments)
(5) Consumer practices & routines	1. Regulation enabling adoption of technologies and business models (e.g., prosuming, energy communities), 2. Regulation enabling behavioural change (e.g., bi-directional charging), reassuring an appropriate pace of change	**Roles: facilitator, promoter** **Abilities: Analytical** (understanding the motivation of consumers; finding an appropriate pace of change/avoiding too far-reaching obligations potentially triggering a defensive attitude) **Resources: Legitimacy** (educating and communicating amendments to the public)
(6) Justice	1. Including a broad justice approach in evaluating regulation regarding end users (e.g., tailor regulation to low-income households: fees and charges need to be fairly distributed) 2. Fair market conditions for all technologies and systems involved (see 2-Multi-system interactions) (e.g., regulation, such as communication standards, may not favour systems/actor groups)	**Roles: observer, mitigator, warner** **Abilities: analytical** (assessing justice related aspects, e.g., market conditions, conditions of user groups); **political** (communicating justice related concerns; equal treatment of all user groups and technologies) **Resources: knowledge** (designing non-discriminatory conditions for all user groups and technologies)
(7) International dynamics	1. Aligning regulation with transnationally valid policies (e.g., EU legislation needs to be transposed to the national scale); 2. Transnationally valid standards (e.g., transnationally harmonised smart-meters and communication standards, for example, for charging)	**Roles: moderator** **Abilities: analytical** (analysing EU legislation); **coordination** (inter-organisational cooperation across compartments and scales) **Resources: human** (integrating and coordination integration of EU legislation), **knowledge** (familiarity with EU regulation
(8) Governance	1. Stronger vertical coordination required across spatial scales (e.g., transposing supranational regulation into national level and communicating national interests to supranational level); 2. Stronger horizontal coordination required due to cross-system business models, standards (e.g., smart meters) 3. Consistent and coherent regulation across levels and systems required.	**Roles: moderator** **Abilities: political** (solving tensions between organisations), **analytical** (analysing EU legislation); **coordination** (vertical and horizontal inter-organisational cooperation across compartments and scales); **Resources: human** (integrating and coordination integration of EU legislation), **knowledge** (getting familiar with EU regulation), **mandate** (clear responsibilities for implementing EU legislation)

5.2. Enhancing regulatory capacity for acceleration: from 'maintaining' to 'creating'

Based on these four regulatory implications and our further findings, we argue that regulators need to enhance their regulatory capacity – the specific interplay of roles, abilities and resources – to be able to tackle the challenges arising in the acceleration phase of net-zero transitions. While in early phases of such socio-technical transitions, the roles of promoter, initiator and lead user are crucial (Borrás et al., 2024), for instance by introducing standards for innovations, our findings emphasise the roles of moderator and gate keeper as well as observer, warner and mititgator for aligning regulation in the acceleration phase. In light of multi-system interactions, the highly contested amendments require governing entities to moderate between divergent interests and to fill a gatekeeper role assuring equal access for all relevant actors (Käsbohrer et al., 2024). For example, as shown by the cancelled draft

law on the controllability of electrical loads (§14a EnWG), enhanced political abilities are necessary for moving forward, in particular, regarding stakeholder engagement and consensus building. In addition, analytical and learning abilities accompanied by knowledge resources are relevant for scrutinising particular interests and for understanding market dynamics and the effects of regulatory changes on business models in the sense of a co-evolution between policymaking and socio-technical change (Edmondson et al., 2019).

Correspondingly, our case study reveals highly dynamic regulatory state capacities and more radical regulatory changes in the second period. Indeed, almost all interviewees from both industry organisations, regulatory agencies and the BMWK emphasise the driving influence of the new government coming into office at the end of 2021, referring to a stronger 'political will' to accelerate the net-zero energy transition in Germany. Our framework helps us to explain these accelerating dynamics by identifying changes in roles, resources and abilities, differentiating between the ministry in charge (BMWK, led by the Green Party) and its regulatory agency (BNetzA).

Regarding the former, we find three major changes with the Ministry of Economic Affairs and Climate Action (BMWK). First, the personnel in BMWK has been increased, hiring further employees experienced in the field of renewables and storage technologies, leading to an increased knowledge on the potentials of residential storages. Second, in operational terms, new departments, procedures and meeting formats have been established enhancing the network resources of employees. Third, the higher level of 'political will' serves as a resource in the form of a strong political mandate establishing clear and ambitious targets, with policy and regulatory change leading to an increase in its legitimacy as additional resource. More specifically, the target of the new BMWK leadership to promote photovoltaics led to a re-evaluation of storage systems as complementary technology necessary for the system integration of residential photovoltaic systems. Taken together, the example of the BMWK shows how regulatory state capacity can be built from inside the organisation itself after a change in political leadership.

Regarding the latter, we find that the Federal Network Agency (BNetzA) is characterised by a form of public leadership, which leaves it with more room for maneuver despite changes in governments. However, while more independent from political trends and usually arguing based on technocratic arguments, the regulatory agency BNetzA also underwent a change in their regulatory state capacity from a rather critical attitude towards storage systems to one of promoting and facilitating their system integration by means of drafting regulatory amendments therefore. Importantly, its role itself facilitated this change. As observer, warner and mitigator, the changing socio-technical environment rather than internal changes have been the driving force for this change in roles, in particular the critical grid conditions due to expanding residential photovoltaics and the growing potential of front-of-the-meter services involving photovoltaics, storages and electric vehicles in mitigating this issue. Thus, a BNetzA representative pointed to learning and reflexivity having occurred over time; recognising that the potential of storage systems in contributing to a secure electricity supply has long been underestimated. In conclusion, the regulator with its legislative influence arising from its legitimacy due to expertise and experience, is crucial for regulatory change needed for the acceleration of net-zero transitions.

5.3. Policy implications for accelerating net-zero transitions through regulatory change

While the German context might show some peculiarities, such as the strong prevalence of residential photovoltaics or the nuclear phase-out and thus reliance on a high share of renewables in the future net-zero electricity system, we still derive five more general recommendations for policymaking and in particular for regulators and their regulatory state capacity for accelerating net-zero transitions.

First, by assigning regulators with a new role to proactively redesign the electricity market to make it fit for the net-zero future early on, such transitions can be accelerated. While the challenge of 'whole system change' is unique to the acceleration phase, taking account of a grid-oriented integration of storage systems into the electricity system already in the emergence phase would have accelerated their diffusion. As our case has shown, the re-evaluation of storage systems as mitigatory technology for critical grid conditions enhanced the endeavours for regulatory changes, but if this would happen earlier in less advanced jurisdictions, socio-technical change could be accelerated there.

Second, we find a crucial role for learning abilities in regulatory state capacity. In this regard, we argue that the openness for learning should be actively pursued and, if possible, fostered by operational procedures, such as non-compartmentalised information exchange. This in turn may help with the reorientation of roles and resulting regulatory change fostering the acceleration of net-zero energy transitions.

Third, communication deficits as prerequisite for better coordination should be addressed, thereby tackling a potential barrier to political consensus – in two ways: on the one hand, regulators complained that industry experts and associations do not communicate innovative business models along with the respective regulatory barriers with sufficient clarity; on the other hand, industry stakeholders criticised the regulators for the high complexity and thus incomprehensibility of regulation.

Fourth, in response, regulators should strive for reducing regulatory complexity, particularly associated with the electricity market design, as overarching design principle in policymaking. Our empirical material suggests that the high complexity of regulation delays or even prevents the regulatory task of reconceptualising the electricity market design. Regulators should not shy away from more radical steps, even if this no longer serves particular interests.

Finally, regulators should strive to mitigate potential uncertainties in markets, such as regarding their perceived need for a front-of-the-meter system integration of photovoltaics and residential storage systems and the remuneration of grid services, instead of evoking further uncertainty. In order to ensure investment reliability, regulators may aim at a clear regulation for the use cases of new technologies (e.g., grid services) and avoid numerous and inconsistent amendments or uncertainties in mandated responsibilities.

6. Conclusion

The paper in hand has addressed the question of what regulatory state capacity is necessary to tackle regulatory implications unique to the acceleration phase of net-zero energy transitions, thereby bridging the literature on acceleration challenges and policy implications with the literature on transformative capacities. Based on a narrow understanding of regulation as one specific type of policies, we derive regulatory implications resulting from acceleration challenges and investigated the necessary regulatory state capacity by differentiating between roles, abilities and resources. The resulting analytical framework is applied to the market for residential storages systems in Germany.

Our findings reveal the relevance of the challenges 'whole system change' and 'expansion and contestation'. The importance of the former results from the need of integrating storage systems into the electricity system for mitigating critical grid conditions due to expanding residential photovoltaics. Thereby, learning and reflexivity led to a re-evaluation of storage systems. 'Expansion and contestation' is a cross-cutting challenge interacting with the coordination challenge of implementing EU legislation and multi-system interactions given divergent interests and advocacy work stemming from multiple systems. Correspondingly, the roles of gatekeeper and moderator as well as political abilities are of high relevance. While the changing attitude towards residential storages in the BNetzA is based on its role as observer, warner and mitigator embedded in a changing socio-technical environment, the changing regulatory capacity in the BMWK is triggered by the change in leadership built from inside the organisation itself.

A limitation of our case study lies in establishing causality between regulatory capacities and regulatory change, given, for instance, the delayed introduction of smart meters hampering the system integration of storage systems as rival explanation. Furthermore, given our focus on the organisational level of regulatory state capacity, the interplay with the systemic and individual level of such capacity warrants future research. Future research could also extend our analytical framework to address not only regulatory change and regulatory state capacity, but to investigate policy change and required state capacities for policy makers changing policy mixes composed of different types of instruments to tackle acceleration challenges. Finally, in light of the unique socio-political context of German electricity regulation, the framework would benefit from being applied to other institutional architectures, like a stronger intertwining of regulation and market-based instruments, and sectors with other characteristics, such as a stronger influence of international dynamics. Notwithstanding, our research has revealed important overarching insights and key policy implications of relevance for facilitating regulatory change as lever for accelerating net-zero energy transitions.

CRediT authorship contribution statement

Andrea Käsbohrer: Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **Karoline S. Rogge:** Writing – review & editing, Visualization, Methodology, Funding acquisition, Conceptualization. **Hans-Martin Zademach:** Writing – review & editing, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors do not have any competing interests to declare.

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Appendix A

Recent contribution on state actors in governing transitions with emphasis on the used terms and their main research interest, own compilation.

Article	Terminology used for 'state' actors and explanation	Main research interest
Borrás and Edler (2020)	**State:** Governmental action including the notions of 'government' (collective action through the exercise of legislative, executive or judicial power) and 'public policy' (concrete actions and initiatives that give concrete 'life' to the general statements/decisions of the government)	Conceptualisation of roles of the state in the context of distinct modes of governance of socio-technical systems.
Braams et al. (2021)	**Government:** Literature review using the terms: 'government', 'state', 'ministry', 'public policy', 'administration', 'bureaucracy', 'policy makers', 'public sector', and 'civil servant'	Literature review on the transition tasks the transitions literature attributes to government. These tasks are set off against the normative arguments of the Public Administration (PA) traditions that legitimise government action.
Braams et al. (2022)	**Civil service:** Employees of the Dutch Infrastructure and Water Management (I&W) ministry	Civil servants' role perception within the institutional structures of their ministry, when executing transition tasks, in the light of Public administration traditions.
Braams et al. (2023)	**Civil service:** Employees of the Dutch Infrastructure and Water Management (I&W) ministry	Civil servants' handling of resistance and tactics to execute government transition tasks.
Borrás et al. (2024)	**Public sector organisations:** Literature review including articles dealing with 'public sector organisations', which can be understood as governments, municipalities, public administrators, agencies, public actors, or similar. The authors also consider 'governance', 'policy', 'organisations' capacity'.	Conceptualisation of public sector organisations' transformative capacity (consisting of organisational roles, resources, and skills) based on a literature review.
Song et al. (2023)	**Governing entities (building on Ossenbrink et al. 2019):** Governing entities refer to the public actors 'in charge of the design, implementation, and governance of the focal policy mix' (p. 3).	Social network analysis on interactions of governing entities in the acceleration phase of transitions.
Rogge and Song (2025)	**Governing entities:** See Song et al. (2023)	Conceptualisation of framework incorporating three conceptual components – acceleration challenges, policy mix intervention points, and types of policy capacities – enabling the identification of critical capacities in the acceleration phase of sustainability transitions.

Appendix B

Overview of working group meetings of observed industry association in the electricity system.

No.	Topic	Date
1	Energy law (working group)	Sep 2020
2	Energy politics (working group)	Sep 2020
3	Task force for EEG amendment	Sep 2020
4	Energy politics working group (presentation by member of EU parliament)	Sep 2020
5	Residential storage systems (working group)	Oct 2020
6	Finance and Investments (working group)	Oct 2020
7	Workshop on residential storage systems	Nov 2020
8	Storage technologies (working group)	Nov 2020
9	Standards and quality criteria (working group)	Nov 2020
10	Trade fair about battery storage systems	Nov 2020
11	Energy law (working group)	Dec 2020
12	Residential storage systems (working group)	Dec 2020
13	Task Force for EnWG amendment	Jan 2021
14	Energy law (working group)	Feb 2021
15	Residential storage systems (working group)	Feb 2021
16	Trade fair on residential and industry storage systems	Mar 2021
17	International market developments (working group)	Mar 2021
18	Energy law (working group)	Apr 2021
19	Energy politics (working group)	Apr 2021
20	International market development (working group)	Apr 2021
21	Workshop on storage systems and manufacturing industry	Apr 2021
22	Storage technologies (working group)	May 2021
23	Energy law (working group)	May 2021
24	Residential storage systems (working group)	Jun 2021
25	Task force Smart Meter Gateway	Jul 2021
26	Energy politics (working group)	Sep 2021
27	Energy law (working group)	Oct 2021
28	Energy law (working group)	Nov 2021
29	Storage technologies (working group)	Feb 2022
30	Energy law (working group)	Feb 2022
31	Energy law (working group)	Apr 2022
32	Residential storage systems (working group)	May 2022
33	Workshop on regulation of fast charging	Jun 2022
34	Energy law (working group)	Sep 2022
35	Storage technologies (working group)	Sep 2022
36	Residential storage systems (working group)	Sep 2022
37	Mobility (working group)	Sep 2022
38	Task force on §14a EnWG	Oct 2022
39	Energy law (working group)	Nov 2022
40	Task force residential storage systems	Jan 2023
41	Residential storage systems (working group)	Feb 2023
42	Mobility (working group)	Feb 2023
43	Energy law (working grou)	Apr 2023
44	Mobility (working group)	Apr 2023

Appendix C

Scheme of relevant codes including the number of coded text passages.

Code	Frequency	Code	Frequency	Code	Frequency	Code	Frequency
1 Challenges		**2 Roles**		**3 Resources**		**4 Skills**	
1.1 inno_whole_syst	76	2.1 Designer	4	3.1 phys_res	0	4.1 analytical_skills	31
1.2 MSI	27	2.2 Initiator	0	3.2 human_res	18	4.2 operational_skills	18
1.3 resist	11	2.3 Facilitator	4	3.3 finan_res	3	4.3 coordination_skills	23
1.4 contestation	6	2.4 Opportunist	3	3.4 know_res	13	4.4 learning_skills	26
1.4.1 intern	3	2.5 Promoter	6	3.5 legit_res	6	4.5 political_skills	
1.4.2 extern	45	2.6 Gatekeeper	5	3.6 mandate_res	13	4.5.1 intern	8
1.5 user_practices	11	2.7 Moderator	5	3.7 network_res	3	4.5.2 extern	54
1.6 justice	10	2.8 Enabler	1	3.8 cult_res	4		
1.7 intern_dyn	2	2.9 Lead-user	0				
1.8 governance	0	2.10 Direction	11				
1.8.1 vertikal	21	2.11 Watchdog	7				
1.8.2 horizontal	17	2.12 Mitigator	10				
1.9 uncertainty	22	2.13 Warner	13				
1.10 context Germany	19	2.14 Observer	5				
		2.15 Guarantor	5				

Appendix D

Exemplary interview material for acceleration challenges, regulatory implications, and regulatory state capacity (roles, abilities, and resources).

Category	Illustrative Quotes – Period 1: Focus on Maintaining	Illustrative Quotes – Period 2: Focus on Creating
Acceleration challenges	**1-WHO:** "*Because you come from an existing system and nobody really dares to tackle it. The system is based on three concepts: generation, transport, consumption. So a very clear top-down system. Coal-fired power stations and nuclear power stations produce electricity, which is transported down via the transmission network and the distribution network and consumed there. And you can still see in many regulations in energy law that this logic lies behind it and nobody has ever fundamentally tackled it […], while our energy system has changed completely and now generation also essentially takes place at the distribution network level and implementing this in the legal framework that we have and which has also grown enormously over the last few decades is just incredibly complicated.*" (Interview 12) **2-MSI:** *"If I have a PV system on a single-family house and maybe a storage unit in the basement and maybe a charging station, then theoretically I have to install up to 7–8 measuring devices. And even then in some cases is it hardly possible to keep this amount of electricity separate. That is the requirement at the moment. And there has been enourmous political pressure recently to simplify things so that these small storage facilities can also claim this exemption from the EEG surcharge in the future."* (Interview 12) *"Life is not a request concert. They [automobile manufacturers] should not overestimate their role. There are also other industry sectors, which do not want to pay their discounts."* (Interview 17) **3-DEC:** *„They [the government] actually wrote down an answer for each of these requests [for charge exemptions]. In some cases it was highly counterproductive. And that's why the rules are so incredibly complicated […] And then there was the shitstorm against the Federal Network Agency and also against the legislator: "You want everything to be so complicated." And in truth it is like this: "You want to have such insanely complicated privileges, you want it to be like this." [industry stakeholders]* (Interview 14) *"You would of course have to overcome incredible resistance, because there are sectors that are strongly represented in terms of lobbying and that also benefit greatly from the current legal framework. So everyone is dependent on some kind of privilege when it comes to taxes and surcharges. So no matter what you do, you would hurt a lot of people."* (Interview 12) *"Because if I make an exception or special regulation in one place, then I have to make adjustments in 20 other places. Looking at EEG and EnWG, you have actually long since lost track. This has reached a level of complexity that is almost impossible to understand."* (Interview 12) *„So there is still the position there [BMWK and BNetzA], based on various studies that are now a few years old, that storage is not actually needed for the energy system, that it is still possible at the moment through load shifting and other methods, as long as we still have gas power plants and the like in the system, and it is cheaper to balance the fluctuations from sun and wind in other ways."* (Interview 12) *"The Federal Network Agency advises the BMWI and then we find all of these restrictive issues in the EnWG in the amendment. And then you are not only fighting against the Federal Network Agency, but also against the BMWI."* (Interview 11) *"The regulatory authority makes everything very complicated, so that it can practically no longer be understood by anyone who does not have at least 10 years of professional experience in this area."* (Interview 1) **4-EXP:** *"Regulation is now a field in which many consultants, consulting firms and law firms are active. When there is a change to the legal basis or regulations, there is a lot of contestation about it."* (Interview 17) *"The storage lobby has always made very, very high demands and always trumpeted 'Storages are not generators at all!' […] totally insatiable, they never stop demanding."* (Interview 39) **5-CON:** *"And the Federal Network Agency has always taken an extremely negative stance on storages and self-consumption. […] They could always assert themselves, because they always thought only in economic terms. […] And they never understood that this is not an incentive for customers, but that customers buy all kinds of things to increase their self-consumption. They now buy heat pumps, electric vehicles. Anything what politicians want. So that they can better use the electricity they generate themselves."* (Interview 11) **6-JUS:** *"It's always about optimising myself outside of the system. I continue to use all system services, but I don't pay for them. That's the motivation behind these things [residential storages]."* (Interview 14)	**1-WHO:** **"***There are approaches from individual companies […], which offer the possibility to control the storages from outside. This is going in the right direction, but we cannot estimate, don't have any figures about the share of storages, which can be controlled from outside. This is probably a small proportion."* (Interview 38) *"The underlying idea is […] that the* 9 GW *of small storages, that we have, with a still increasing trend, could actually be helpful, if they were managed in direct marketing (Direktvermarktung), then the midday electricity is fed in, stored in, if it is not curtailed, depending on what is economically convenient, but as long as there is still room in the storage, it will be put in the storage, which helps and is also fun for direct marketers." (Interview 39)* **2-MSI:** *"That's [getting access to politics] very difficult, but of course brands like [automobile manufacturer] increase your reputation. One is taken more seriously, if you come there with a decent brand compared to three, four start-ups and SMUs."* (Interview 27) *"We hope, that one day every wallbox will have the same interface, every heat pump the same interface, in order to regulate all elements with one interface. Then, for me personally, the whole topic of bidirectional vehicles is important. The regulation is really not that far yet, vehicle-to-home has been clarified, but vehicle-to-grid is a huge question mark. And also, that it will be standardised, a uniform communication protocol. […] because it's inconvenient, if the energy management system is not compatible with the bidirectional vehicle."* (Interview 30) *„A residential storage is typically somewhere in the range between 5 and 10 kwh. An electric vehicle is by a factor of 10 higher. […] If electric cars could be operated flexibly, charged flexibly, if there was an incentive for this, we would have a much greater control potential, or flexibility potential, than with private home storage systems."* (Interview 38) *"The core problem has not been solved. The core problem is ultimately energy economic balancing of, let's say, prosumers.[…] What gets clearly more interesting and exciting with e-mobility and heat pumps […] and also regarding the new [pv] expansion speed in the energy transition. I'm optimistic, that we will see a clear run-up of PV. So, that's not a question of whether we should do that, locally optimising, energy communities, energy sharing, but that this will be a technical necessity, since our infrastructure, the electricity grid, is scarce. The regulatory environment is not aligned to this speed. It is a good idea to find ways and means to deal well with this scarce infrastructure. That could be systems with storages, in particular e-mobility, if they get the corresponding signals, and I don't refer to price signals, which are important, but also grid signals […] we need to measure the voltage […] Then we can optimise accordingly."* (Interview 32) **3-DEC**: *"Simply because [automobile manufacturer] is putting its full lobbying power into the systems and threatening. Due to this pressure, in particular of [automobile manufacturer], the topic of bidirectionality is maybe developed and further discussed, but there is the risk of some kind of preferential treatment, just to make [automobile manufacturer] happy, which is not actually right or relevant from a system perspective. Some kind of exemption for mobile storages is now being developed, but we don't need special regulation for mobile storages in cars, we need new regulation in general."* (Interview 35) **4-EXP:** *"I think that industry associations or a part of the industry associations are not capable of really understanding the model [electricity market design], which we currently have, and certainly don't have the courage or capability or structures whatever to explain their members what is going on here."* (Interview 39) *"Whenever the grid is involved, there is a need to check whether the grid fees for storage are appropriate. This can of course be the case with these energy communities, but we have a bit of a problem in that it is not exactly clear what these thought models and grid concepts actually are […] It's just that the needs and concepts are actually presented to us relatively rarely in concrete terms. […] It's just a vague general picture that is being painted that something isn't right, but it's not described in detail. And that's bad, of course, because if you want to solve a problem, you have to know what the problem looks like."* (Interview 33) *„It's simply not true. There are these EU guidelines that are so clear and that say, storages here and there, and you have to do this, they simply don't exist. Of course, this is always claimed. […] That is the lobby tactic.*" (Interview 33) *"[…] whether it is a good strategy to demand that EU directives are not demanded. I think the strategy was bad and is bad to demand: It's written there and, thus, we want it. It's already allowed, but not practical. To say that this regulation has not been implemented, without being specific about what needs to be done, is a strategy that has not been successful in recent years and will not be successful."* (Interview 32) **5-CON:**

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Category	Illustrative Quotes – Period 1: Focus on Maintaining	Illustrative Quotes – Period 2: Focus on Creating
	"Unfortunately, it is often the case that when they use electricity from the grid, they use the full amount because the sun is not shining and the storage is empty. That means that the DSO must still maintain full capacity in the grid. […] When it comes to regulation, if one doesn't pay, the other will. Then the others have to pay for the one." (Interview 17) **8-GOV:** *"So what we can see is that the influence of European legislation is still totally underestimated in Germany. […] So far, the strategy has been to implement these guidelines in an absolutely minimal way."* (Interview 12) *"The EU is also doing good things. For example, the EEG exemption on self-consumed electricity. The limit in Germany was previously 10 KW peak, and now the limit has been raised to 30 KW peak due to the EU. That would not have happened voluntarily in Germany."* (Interview 10) *"There is this guideline about increasing the exemption from the EEG surcharge for self-consumption. The de-minimis limit has been at 10 kw for 10,000 kmw per year and in the EU regulation it says 30 kw. How we had to fight for the BMWI to simply implement this requirement one-to-one in the EEG. It really took long."* (Interview 11)	*„The motivation of an energy transition at home is very big. Most of storage owners don't calculate it down to the last cent to see if it's really worth it. They just think it's really cool and nice when I can fill up my storage with the electricity I generate myself or charge my cell phone every day. […] the psychological dimension of it, must not be underestimated."* (Interview 33) *Now, this government has tried to indoctrinate people and force them to do something. They are clearly resisting this. And that is now leading to everything being slowed down and decelerated again, so as not to scare people off any more. Finding the right pace is difficult."* (Interview 35) **6-JUS:** *„Regulation is always, one wins, one loses. There is no regulation where everyone wins. If I exempt someone from taxes, the other one pays. […] Regulation decides, who has to raise this amount x '[to finance the grid]. A storage system doesn't have to pay this amount x. Well, then the pensioners in the rented apartment pay. These are all things that you have to think about."* (Interview 33) **7- INT:** *"Although smart meters are ultimately there to provide a certain degree of variability in electricity end-customer tariffs, then this should be harmonised across Europe […] Nevertheless, everyone understands something different about smart meters. Things, which are based on a deficient EU-legislation […] So every member state has made up its own thing."* (Interview 33) **8-GOV:** *"It is largely determined at the European level what such an energy market design should look like. There is of course a lot of scope for design at the national level, but the fundamental questions are clarified at the European level."* (Interview 32) *"No, that is not the case, what is specified will be implemented. Of course, sometimes there are questions regarding the content by EU legislation. And then the challenge is to implement it in such a way that you make the best of it, but to say that's nonsense, we won't implement it, that doesn't exist. We implement European guidelines to the best of our knowledge and belief. […] And I think, for example, when it comes to residential storage, it's simply the case that the level of detail in the standard doesn't require it to be regulated in one way or another." (Interview 33)* *"As far as grid tariff regulation is concerned, I have to say that the European legal framework is extremely contradictory."* (Interview 33)
Roles	*"In the documents, which we published at that time, we had already foreseen exactly the problem that I am about to describe - the so-called power peaks. […] We warned about it in time and nobody listened to us, nobody. […] We proposed this at the time because we wanted to make the expansion of solar energy future-proof; that was our argument at the time."* (Interview 39) *"In principle, you would have to imagine the energy system of the future and what it would look like and then you would have to say: "OK, we need this and that legal framework for that."* (Interview 12) *"The problem [unfair grid fees] I would say is being monitored and if it continues to gain the upper hand, then we really have to consider whether there should be some kind of penalty payment for self-suppliers, some kind of contribution, similar to a building cost subsidy, we are thinking of a fixed amount to compensate so that things become fairer again overall."* (Interview 17)	*"Regarding the current legal environment in EEG and EnWG, I have to say: What this government has already brought about - in terms of simplifications - we have not had that in the last 16 years. It's incredible, how fast things are possible and we are quite fascinated by the way how this is discussed right now."* (Interview 25) "*Ultimately, the task of regulation is not to dictate anything, but the task is to make things possible. So that there aren't any drawbacks, which make any concepts uneconomical per se. In this case, we would […] give a forecast of what exactly and how will be changed."* (Interview 33) *"Our department is concerned with the expansion of renewables as well as with the issue of system integration of renewables. […] That's why we're concerned with the topic of the market as well as with the topic of lines and grids. In other words, with physics and with the topic of the market. How can we obtain power in a way that is beneficial to the system, without putting any kind of cost or physical burden on the system? This now also includes the topic of PV and charging electric vehicles, which is the equivalent in the area of mobility." (Interview 38)*
Abilities	"*As a subordinate authority of the Ministry of Economic Affairs, we naturally have fairly close contact with our mother authority. We in the department are trying and putting a lot of energy into maintaining this contact very closely, also personally, actually with endless assistance and support activities, advisory services, meetings and actually personal proximity, we go there."* (Interview 14) *"And then it is passed on to the departmental coordination. That is the departmental and association hearing. So the actual way would be a departmental coordination, then an association coordination. Because things are always so incredibly hectic with the EEG, it is often done at the same time. That is structurally very bad, but that is how it is."* (Interview 14) *"We sometimes have statements with a 48-h or 24-h response period between Christmas and New Year. Things like that happen. With the fast-charging law, it was 48 h between Christmas and New Year. And we have that all the time."* (Interview 16)	*"My perception has changed completely and, thus, of course my opinion, I had considered it particularly difficult at the time and now I realise, or have realised for some time, that the existence of something that can be marketed is the prerequisite for being able to do direct marketing with small systems. This means, you need an electric vehicle, a heat pump, a storage system, you need something like that, preferably all three, to make direct marketing really fun. […] Secondly, I didn't see - and this is where I completely changed my mind - that there could actually be a mass market that would collect all of these super-small power storage units and actually integrate them into the market. I simply didn't think that was possible."* (Interview 39) *"This is now really, really demanding with this renewable [EU] directive, because it involves so many legal texts with approval rights, so many ministries and authorities. That's going to be very demanding. Each department has its responsibility for implementation, so we here in the department, we are now doing the grid integration of heat pumps, for example […] Species protection must then be done by the Ministry of the Environment. so of course you have to agree who translates what. This is again an extremely demanding process that requires a great deal of balancing and coordination."* (Interview 33) *"Very large, very good gain in knowledge in the individual topics, but the final coordination of the energy system, so to speak, as it should be and look like in the future is missing. Nobody still dares to define the overall target of what the energy system should really look like at the end of the energy transition, how sector coupling is realised in practice, how we can ultimately bring the rooftop systems and house storage and industrial storage and industrial rooftop systems into the process heat, how we want to bring this into the heat transition, how we want to bring this into mobility. There is still a very strong silo mentality, one does the Ministry of Transport, the other does the industry side in the Ministry of Economics, the other does the energy side in the Ministry."* (Interview 35)

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Category	Illustrative Quotes – Period 1: Focus on Maintaining	Illustrative Quotes – Period 2: Focus on Creating
Resources	*"The BMWi does not write such regulations, especially on these topics, without consulting the BNetzA, because the BNetzA has more people and more expertise, especially when it comes to the technical details. The BMWi is already quite thin in terms of personnel, especially when it comes to the electricity department., i.e. at the moment they don't have the people to be as involved in every issue as the BNetzA. This is why, usually the BnetzA is requested. I know of many cases where BNetzA wrote the corresponding paragraphs in the EEG, including the justification for the law."* (Interview 3) *"The BNetzA was initially the wrong contact [for implementing EU legislation], but this has now changed due to the reorganisation of roles; the BNetzA is now the right contact. This was not the case before, it was the Ministry of Economic Affairs […] This combination led to the situation, that some claimed implementation from the non-responsible actor, from the BNetzA." (Interview 32)*	*"Nevertheless, at the moment, the Ministry of Economic Affairs is green and the Ministry of Transport is yellow. And that alone means that conflicts of interest and tensions arise because, of course, one side wants to grant the other as little as possible. Of course, they are in a coalition, but nevertheless there is a time after the coalition and everyone wants to inherit the best cards for themselves in advance. This is a very (very) big shortcoming that we have and that we have always had."* (Interview 26) *"No, it [deadlines for association hearings] is still very short-term. It has improved a little over the course of the legislative period. The procedures in the ministry have become a little more well-established. Perhaps not so much is happening in parallel and at the same time anymore."* (Interview 35) *"This started with the fact that particularly the FDP parliamentary group in the German Bundestag pushed and pressed and pulled and did everything it could to ensure that the storage systems could actually be better integrated into the market. And they saw the so-called exclusivity principle [separation of green and conventional electricity] as their main opponent or as their main problem."* (Interview 39) *"It must be said that we had already addressed and justified all of these demands hundreds of thousands of times under the last government. […] And that is simply a completely different issue with this government. They want these topics. And if you want something, then you do those topics. […] They are now simply implementing exactly what we should have implemented at the European level a long time ago. All these pro-sumer issues."* (Interview 25) *"The BNetzA is more likely to have energy experts, but in the Ministry of Economic Affairs and Climate Action we do not necessarily have energy market experts in the departments. And the ministry itself does not actually have the competence, but the competence has to come from outside, also from the stakeholders and ultimately from the evil lobbyists."* (Interview 35) *"We proposed this rule to the ministry and the ministry thought about how to sell it to the commission, which is also very difficult. It has been difficult for the Ministry to say that the regulation we issued last year will be cancelled again this year and replaced by another one. This is also extremely complicated for the parties. That is why it is absolutely necessary to talk to the parties in advance."* (Interview 39) *"The top level has now understood, at the political level, that we need storages. […] So to speak, at a low-threshold technical level, it has also been understood, but I have to go through this very hard middle structure, […] the department, which deals with storage, these are all relatively new, young BMWK employees and now this knowledge has to be passed through this concrete block in the ministry, which says, we have never needed that and I have been sitting here for 30 years."* (Interview 35)

Data availability

Data will be made available on request.

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