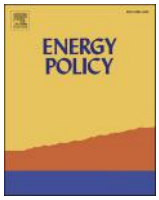
Energy Policy 209 (2026) 115002

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol



Synthesised innovation drivers and barriers in the energy sector

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ARTICLE INFO

Keywords:
Innovation
Energy
Driver
Barrier
Literature review
Culture
Investment

ABSTRACT

In a structured literature review, this study unifies the fragmented body of literature on drivers and barriers to innovation in the energy sector. A total of 273 publications were screened for relevance. 64 met the predefined criteria and were included in the dataset. The study makes unique contributions by developing the intersections of the drivers and barriers in four domains: energy companies can influence (1) the curse of incumbency on innovation and (2) the importance of economic performance and value creation of innovation, whereas policymakers have a strong lever on (3) the dual role of regulation and policy for innovation and (4) the effects of market dynamics on innovation. Moreover, the study reveals an imbalance in the research focus on innovation in the energy sector, with more studies addressing innovation drivers than barriers, which introduces an optimistic narrative. Most identified innovation drivers represent ideal conditions or market conditions beyond the energy sector. In contrast, the innovation barriers offer concrete constraints hindering innovation that can be directly addressed in the energy sector. Therefore, policymakers should emphasise solving embedded problems over promoting non-energy sector-specific enablers. This translates to innovation-friendly policy and regulation considering that energy companies need to simultaneously (1) address high investment costs by forming partnerships with non-energy sector companies, (2) accept the different risk profile of innovation compared to existing products, (3) equip their workforce with the knowledge and skill set to innovate and (4) adapt standards and processes instituted over decades to innovation.

1. Introduction

The concept of innovation is ambiguous. Gijs van Wulfen characterises it as "[…] a feasible relevant offering such as a product, service, process or experience with a viable business model that is perceived as new and is adopted by customers" (Gomes, 2020, p. 156). Kahn (2018) positions innovation as an outcome, a mindset, as well as a process. Others describe innovation as a novelty (de Medeiros et al., 2014) or as a critical economic growth component (Schot and Steinmueller, 2018; Schumpeter, 1939). An essential aspect of innovation is that it can help a company set itself apart from others in terms of processes, services, products, or business models, which sometimes even lead to a competitive advantage (de Medeiros et al., 2014; Zott and Amit, 2010). Christensen (1997) differentiates between sustaining and disruptive innovation: While established companies are efficient at improving existing products (sustaining innovation), they often crumble as novel and initially inferior technologies or services gain market share by being more affordable or convenient (disruptive innovation).

The development of renewables from expensive to viable competitors to fossil fuels is one example of disruptive innovation in the energy industry. Initially supported by subsidies, these technologies expanded their market positions, enhancing their cost-effectiveness and performance with time. Large-scale wind parks and residential solar panels transformed energy generation when the levelized costs of energy (LCOE) of distributed energy resources (DER) decreased (Wainstein and Bumpus, 2016). Power-to-X technologies and storage solutions optimise the use of renewable energy closely linked to load balancers, facilitating flexibility and maintaining grid reliability (IRENA, 2019). Digital and controllable grids unlock the potential to optimise the bidirectional flow of power. Smart meters provide valuable insights into consumption levels and innovate how energy can be priced. In the energy wholesale market, players with more advanced trading software, such as auto traders, create a new level playing field. Energy utilities face competition from new market entrants, especially in sales, making it harder to maintain their customer base and increasing the costs to acquire new customers. In addition, customers can become their own energy

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https://doi.org/10.1016/j.enpol.2025.115002
Received 14 May 2025; Received in revised form 19 November 2025; Accepted 25 November 2025
Available online 30 November 2025
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producers (prosumers), feeding their surplus energy back to the distribution grid and demanding new services from the market, thereby increasing the need for established energy companies to reinvent themselves and innovate their business model (Faerber et al., 2018). Moreover, Artificial Intelligence (AI), Blockchain, or the Internet of Things offer a new customer experience, smarter contracts, and, in the case of AI, it improves the utilisation rate of assets and increases transparency on data.

Thus, innovations in the energy sector span the entire supply chain rather than being concentrated in just one segment (Bryant et al., 2019; Eurelectric, 2013; Richter, 2013a). Even so, companies active in at least two segments of the energy supply chain, subsequently referred to as energy utilities (Mosquera Gutierres et al., 2021), encounter difficulties adapting due to high transaction costs and regulatory complexities.

The effect of innovation on the business model of energy utilities is a growing topic as the energy sector recognises the need to integrate innovations to become more service- and solution-based rather than purely commodity-driven (Boons et al., 2013; Chesbrough, 2010; Helms, 2016; Richter, 2013a, 2013b). Tayal (2017) adds that the trend from a centralised to a decentralised energy system results in higher safety and reliability concerns regarding the infrastructure of energy utilities and declining revenues from stranded assets. Also, the extent of R&D spending to foster innovation in energy utilities has been widely discussed (Bointner, 2014; Y. J. Kim and Wilson, 2019), and so has been the link between energy and sustainability goals and how innovative solutions in energy can reduce CO_2 emissions (Balsalobre et al., 2015; Duscha et al., 2019). Fagerberg et al. (2016), van den Bergh (2013) and Kivimaa and Kern (2016) discussed policy measures and the impact of policies on energy innovation. Other researchers investigated innovation methods applied in the energy sector to improve co-creation in an increasingly interconnected sector (Gjørtler Elkjær et al., 2021) or promote open innovation (Greco et al., 2017).

However, the literature is fragmented and has not yet consolidated what leads or hinders companies active in the energy sector from innovating. Consolidating the innovation drivers and barriers would provide transparency into where they interact and enable policymakers and energy companies to accelerate innovation. Therefore, this research aims to synthesise innovation drivers and barriers for companies in the energy sector into a consolidated view and to reveal their interrelation. Thus, this study addresses the research question: *How do drivers and barriers to innovation in the energy sector interact and converge into domains that shape innovation in the energy sector?*

The subsequent section characterises innovation in the energy sector. It is followed by data collection and analysis using the Energy Framework For Innovation (EFFI), developed for this study, to analyse the drivers and barriers to innovation and their interactions. The EFFI's output is presented in section 4, discussed in section 5, and the conclusions are drawn in section 6.

2. Characteristics of innovation in the energy sector

The *energy sector for electricity*[1] operates as a complex system characterised by multiple interdependent players sharing data, energy and monetary flows, as shown in Fig. 1.

Innovation in this system can be understood through three key aspects: (1) *Innovation methods* describe how an energy company innovates and adopts external knowledge. It provides insights into the strategies and approaches that drive creative breakthroughs and a deeper understanding of how organisations cultivate and sustain innovation in a competitive landscape; (2) *Development process of innovation* introduces the timely sequence and necessary steps to turn ideas into products; and (3) *Measuring innovation* outlines how innovation in the energy sector is tracked.

2.1. Innovation methods

The innovation methods found in the energy sector can be differentiated based on the input of external knowledge to drive innovation (Dahlander and Gann, 2010). The strongest input of external knowledge is mergers and acquisitions (M&A), in which an innovative company is acquired to bring innovation to the buying party. In co-creation, companies jointly develop innovative solutions that can even lead to a joint venture. In the energy sector, types of co-creation can be noticed in the energy solution business, where bundling different products, such as battery and energy management systems, can form a complex peak shaving product (Braunholtz-Speight et al., 2021). Co-creation and collaboration through open innovation enable companies to share their internal knowledge and capabilities, thereby allowing them to benefit from each other's complementary skill sets (Gann, 2005; IEA, 2019; Richter, 2013b). Greco et al. (2017) note that the possibility of attracting external or governmental funding increases, particularly for cross-industrial innovation cooperation in the energy sector. On the other hand, in-house innovation has no external input (Gann, 2005) and is more common on the technological side of the energy industry, such as generation and grid business. Usually, these companies have their own R&D activities (Jamasb and Pollitt, 2015).

2.2. Development process of innovation

The energy innovation process is structured into "Research, Development, Demonstration, Market formation and Diffusion" (Y. J. Kim and Wilson, 2019, p. 3), and these steps are comparable to those in other industries (da Silva et al., 2016). The process starts with researching the topic and forming an idea that will be constructed, hardened in the development phase and demonstrated in a prototype. Finally, the product will be marketed externally and diffused in the market (Kerr et al., 2021). Grubb et al. (2021) highlight the complexity of the energy system, noting that technologies in the energy sector, especially, take time to develop, that they are knowledge- and capital-intensive and that energy utilities dominate the sector. Therefore, they argue that the additional stage *deployment* should be integrated into the innovation process between the stages *Market formation* and *Diffusion*. In the *deployment stage*, the technology is adopted at scale but is still not competitive in terms of cost.

2.3. Measuring innovation

Key Performance Indicators (KPIs) make innovation measurable and indicate a company's innovation activities (Dahlander and Gann, 2010). As noted by Bointner (2014), most papers consider R&D expenditure and the number of patents as KPIs for innovation. In addition, Greco et al. (2017), who study open innovation, also highlight M&A activities as an important indicator of innovation activity. Loredo et al. (2019) and Dahlander and Gann (2010) also propose that *licensing of products* should be included as a KPI to improve processes.

With this foundational understanding of the innovation methods, processes and KPIs in the energy sector, which will be revisited in the discussion and conclusion, the subsequent section outlines the research methodology adopted to address the study's objective, followed by its findings.

3. Methodology

A structured literature review was conducted to investigate the drivers and barriers to innovation of companies in the energy sector (Fig. 1). The study aligns with best practices outlined in academic literature (e.g., Creswell and Creswell, 2018), ensuring a comprehensive and robust coverage of the literature: (1) The startset was built by a

[1] Unless stated otherwise, when referring to the energy sector, this study refers to the energy sector for electricity as illustrated in Fig. 1.

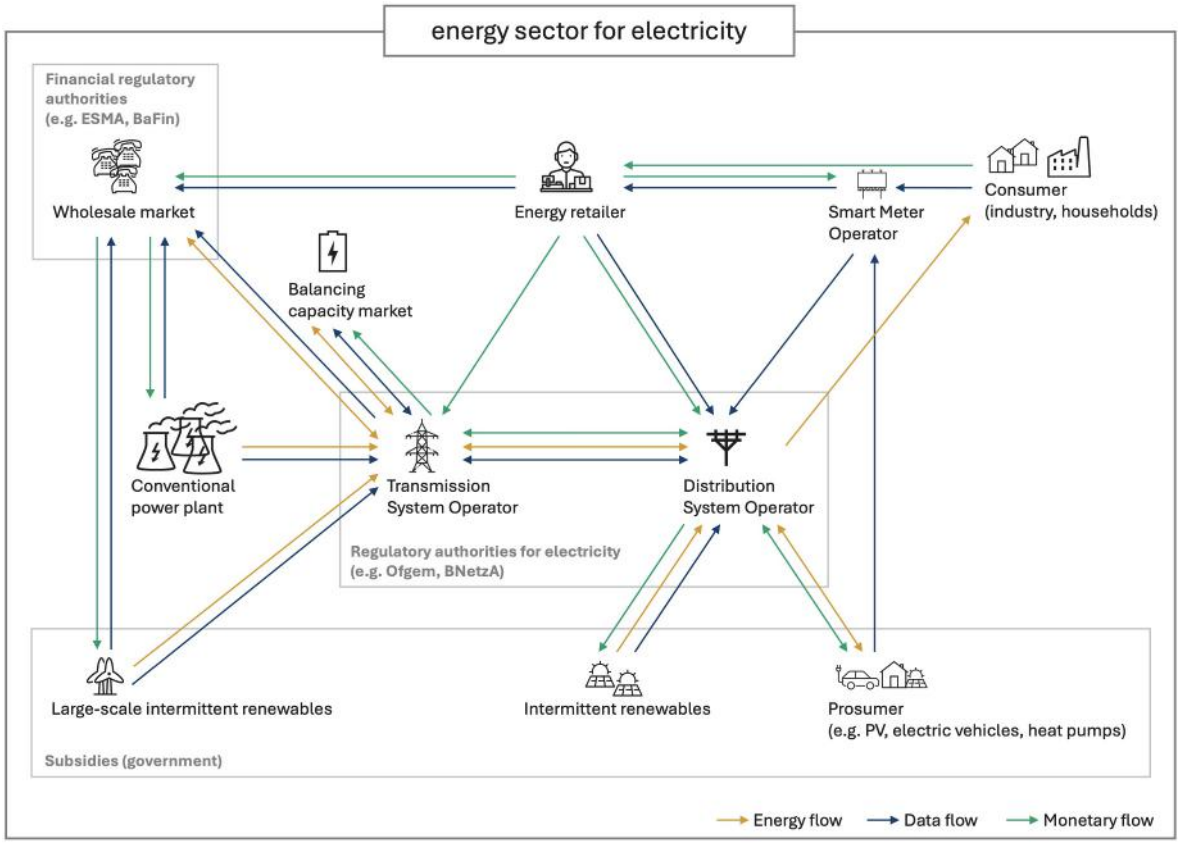

Fig. 1. Simplified schematic of the energy sector for electricity and underlying energy, data and monetary flows across its actors.

structured process of identifying studies through keyword searches. (2) It was enriched and expanded by forward- and backward-looking snowball sampling. (3) It integrated qualitative identification of themes with quantitative analysis of frequencies.

The following section presents the data collection method, including a description of the selection criteria for the papers to be included in the review, their timeframes, the keywords used, and the databases utilised. It is followed by Section 3.2, which outlines how the data was analysed and made comparable to examine clusters of themes.

3.1. Data collection

A two-step approach was chosen to create a comprehensive dataset. In the first step, the sources for the *startset* were selected. As innovation often demands an interdisciplinary approach (Fagerberg, 2006), papers of interest were likely published not only in energy-focused disciplines but also in disciplines such as business administration, economics, or technical areas. Therefore, the search for the startset was not restricted to specific journals. Instead, the publications were found using keyword searches on the search engines *ScienceDirect*, *Web of Science*, and *ResearchGate*.

The initial keyword search used the terms “energy innovation”, “energy and innovation”, and “energy utilities and innovation”. These terms were selected to prioritise conceptually relevant studies analysing innovation processes in the energy sector. Following established guidance for systematic reviews (Snyder, 2019; Tranfield et al., 2003; Webster and Watson, 2002), the keyword search was not used as the sole filtering mechanism but was complemented by additional methodological safeguards. Specifically, the keywords were applied to the Abstract, Title, and Keywords fields, and a broad interdisciplinary search strategy was adopted to capture studies using different terminology across academic domains. We acknowledge that no keyword-based approach can capture the entire body of potentially relevant literature; however, the subsequent multi-stage screening process and complementary snowballing procedures substantially mitigated this limitation.

Because of varying energy market designs across countries, which lead to differences in the organisational structure of energy companies, their capabilities, and where they are allowed to be active in the energy value chain, the scope of the paper selection was limited to published journal articles and book sections relevant to energy innovation in Europe.

In addition, the selection of publications of the startset was limited to a fixed timeframe from 2010 onwards to include only publications after the final phase of the energy sector liberalisation in Europe in 2009, which, among other things, gave customers the right to choose their energy provider and can be considered as the birth hour of the current energy utility structure (Marino et al., 2019).

In the second step, forward- and backward-looking snowball sampling was applied. Here, the startset was screened and regarded as *seed articles* (Lecy and Beatty, 2012), yielding 132 studies. In the backward-looking snowball sampling, the references of the seed articles were screened to identify additional relevant studies. In this round, however, articles published before 2010 were also considered as they were cited in publications within the set timeframe. Then, forward-looking snowball sampling was applied to identify the discourse in the literature initiated by the seed articles. It follows up on how often the seed articles were cited after publication (Naderifar et al., 2017; Wohlin, 2014). It thereby improved the likelihood of finding all current articles on innovation in the energy sector. Finally, backward-looking snowballing was applied to cover studies referenced in forward-looking snowball sampling.

Across Steps 1 and 2, a total of 273 studies were identified, of which 141 stemmed from forward- and backward-looking snowball sampling (see Fig. 2).

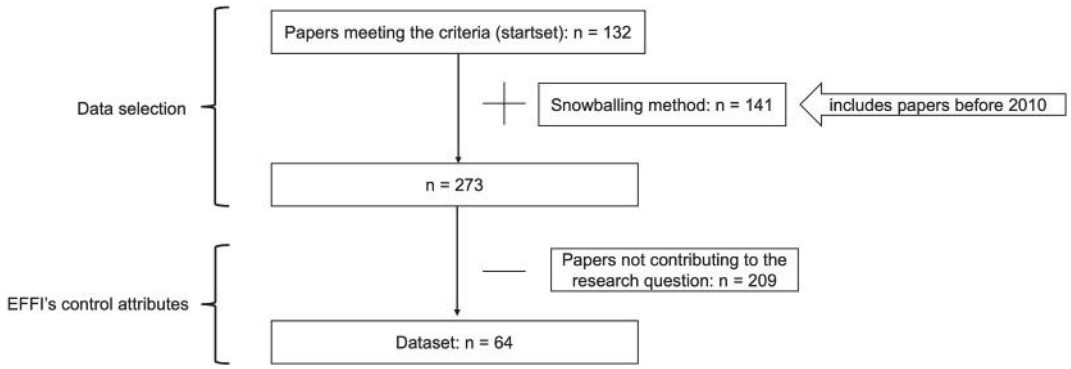

Fig. 2. Data selection process.

3.2. Data analysis

The 273 studies were analysed by applying the analytical framework EFFI (Table 1), developed for this study. The first category of the EFFI framework's Control Attributes served to determine whether each publication substantively contributed to the research question. Following established guidance on transparent and reproducible screening in systematic literature reviews (Snyder, 2019; Tranfield et al., 2003), these attributes were operationalised through three eligibility criteria. First, the publication had to focus on drivers, barriers, or determinants of innovation adoption. Studies were excluded if they mentioned innovation only tangentially or focused exclusively on technical optimisation, engineering performance, or policy modelling without analysing the conditions under which innovation is adopted. Second, the publication needed to address innovation within the electricity-related energy sector, including areas such as generation, networks, storage, and supply, as illustrated in Fig. 1. Articles originating from sectors outside the energy domain were excluded unless they offered clearly transferable conceptual insights relevant to innovation processes in the energy sector. Third, the publication was required to provide an explicit or implicit definition of innovation that aligned with established innovation theory, enabling the extraction and categorisation of drivers and barriers. Publications that used the term *innovation* generically or without conceptual grounding were excluded to maintain analytical consistency.

Applying these criteria resulted in the exclusion of 209 of the initially identified 273 articles (Fig. 2). As noted in systematic literature reviews, such high exclusion rates are common when broad search strategies are combined with rigorous topical and conceptual relevance criteria (Snyder, 2019; Tranfield et al., 2003). The remaining 64 articles constitute the dataset for the subsequent analysis phase.

The second category of the framework, *Driver and Barrier Attributes*, was used to analyse the substantive content of these 64 publications. Drivers of innovation were extracted to identify the conditions and motivations that enable innovation in the energy sector and to understand how they can be strengthened. Barriers to innovation were gathered to capture the obstacles and systemic constraints that impede innovation within energy companies or across the broader energy system.

As the final step in the data analysis, a quantitative analysis was conducted to determine the prevalence of each driver and barrier within the dataset. This involved systematically identifying the drivers and barriers referenced in each study, mapping them to driver or barrier groups (Fig. 3), and tracking their frequency.

In synthesising the findings, all drivers and barriers were treated with equal weight, and each factor was counted once per study. This frequency-based approach is widely used in systematic literature reviews as a transparent means of mapping thematic prominence across heterogeneous bodies of research (Snyder, 2019; Tranfield et al., 2003). The frequency of mention reflects the salience of a factor in the academic discourse rather than its empirical magnitude or practical influence (Gough et al., 2012). Because the reviewed studies employ diverse methodological designs, including qualitative case studies, quantitative surveys, modelling approaches, and conceptual analyses, developing a comparable weighting scheme would introduce additional subjectivity and compromise methodological coherence (Boell and Cecez-Kecmanovic, 2015). Therefore, a frequency-based synthesis was adopted as the most reproducible and methodologically defensible approach for this systematic review (Webster and Watson, 2002).

Although the first author conducted the coding, the analytical process was guided by transparent inclusion and exclusion criteria and explicit categorisation rules documented in the EFFI framework. These rules limit interpretive discretion and ensure that coding decisions remain consistent with the structure of the underlying literature rather than personal judgment. The author also applied a reflexive approach throughout the analysis, continuously reflecting on how their professional background might shape interpretations and taking care to adhere closely to the textual evidence presented in the reviewed studies. The emerging categories, intermediate results and the overall analytical framing were discussed with a supervisory team to ensure conceptual soundness.

Table 1
Energy framework for innovation (EFFI).

Control Attributes	(1) Key topic (2) Energy sector relevance
Driver and Barrier Attributes	(3) Innovation definition (4) Drivers of innovation (5) Barriers to innovation

4. Findings

The following subsections present the drivers and barriers to innovation in the energy sector, as revealed by the EFFI. Since most studies reported multiple drivers or barriers, each of them was recorded separately to reveal its individual frequency, thereby allowing the total count of drivers and barriers to exceed the number of studies in the dataset. Fig. 4 presents an overview of the drivers and barriers to innovation, along with the process from which they emerged.

To stay faithful to how drivers and barriers are represented in the underlying literature, the categories reported reflect the level of granularity used across the reviewed studies. This results in heterogeneous granularity, for instance, broad categories such as *policy and regulation* appear alongside more specific ones, such as *rising energy prices*. Collapsing these into artificially standardised or uniformly broad categories would obscure important distinctions present in the corpus. Such heterogeneity is common in literature-driven syntheses, where categories must reflect the conceptual diversity of the underlying studies rather than be forced into uniform bins (Hoon, 2013; Snyder, 2019). The frequencies reported therefore reflect how factors are represented in the

author	year	title	journal	key topic	energy	innovation in general	barrier	barrier category
			control attributes				drivers and barriers attributes	
Naber, R. et al.	2017	Scaling up sustainable energy innovations	Energy Policy	This paper mobilises literature on the strategic management of experimental niches to explore the upscaling of smart grids in the Netherlands.	yes	"MLP framework builds upon evolutionary and social constructivist approaches to innovation and distinguishes three levels: niche, regime and landscape."	"Legislation can be a challenge for upscaling" (p.353)	regulation and policy
Gjørtler E. L. Horst, M. Nyborg, S.	2021	Identities, innovation, and governance: A systematic review of co-creation in wind energy transitions	Energy Research & Social Science	Co-creation & wind energy	yes	"As an innovation paradigm 'co-creation' is believed to produce more legitimate and inclusive innovation processes..."	"institutional barriers (such as carbon lock-in, contract periods, risk-taking profiles, and lack of openness [52]) and a lack of trust as conditions that increase the difficulty of transitioning to more collaborative forms of interaction and organization" (p.4)	regulation and policy

Fig. 3. Example of process mapping statements to a category.

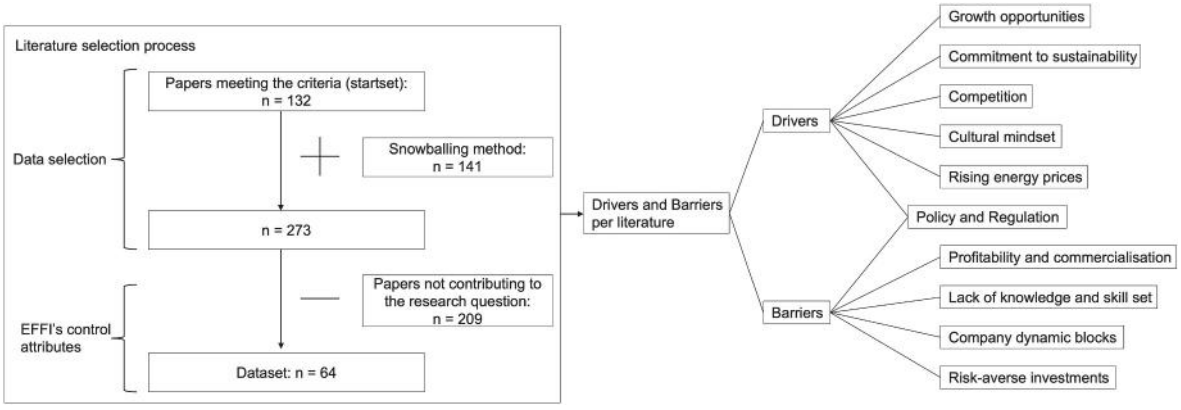

Fig. 4. Innovation drivers and barriers in the energy sector – process and output.

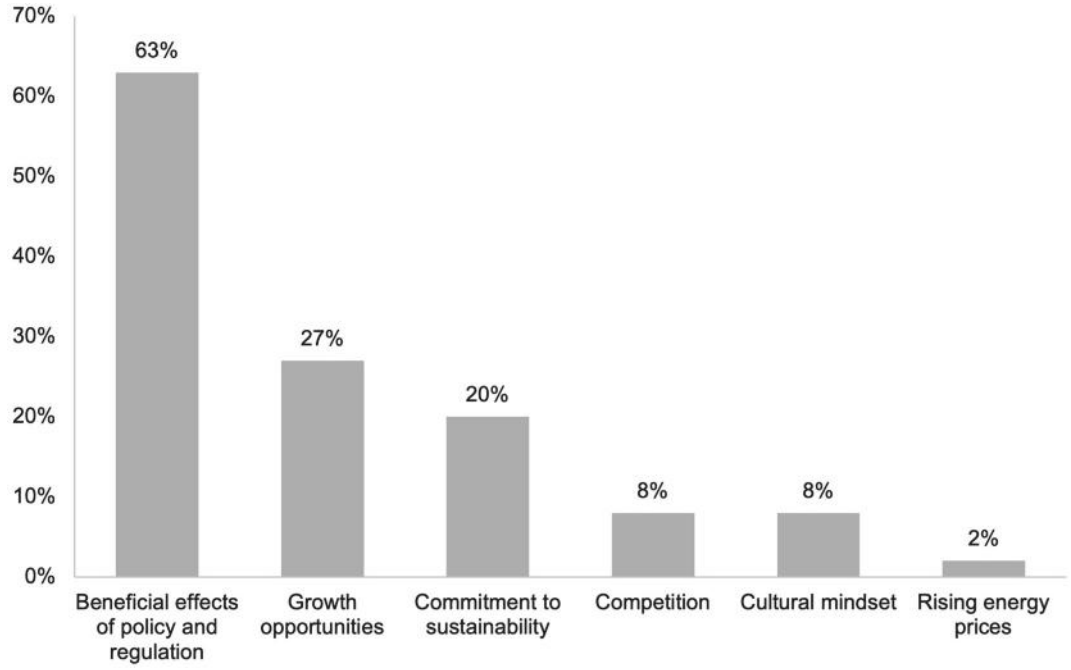

Fig. 5. Percentage of papers in the dataset that report each innovation driver.
Note: Each barrier was analysed independently to account for its individual frequency in the dataset.

literature, rather than implying differences in their intrinsic importance.

4.1. Drivers of innovation

Across the dataset, the motivations for companies to innovate and the dynamics that facilitate innovation are referred to as drivers. In total, six drivers could be synthesised. Fig. 5 illustrates their distribution.

4.1.1. Beneficial effects of policy and regulation

Sixty-three per cent of the dataset describe policy and regulation as a driver. Policy and regulation are crucial throughout the innovation process (OECD, 2015b). According to van den Bergh (2013), "[…] regulation aims to reduce negative, environmental externalities, while innovation policy intends to address positive, knowledge-related externalities […]" (p. 17). Yet, policymakers' influence levels strongly depend on the instrument chosen. For example, grants and public research efforts can be directly steered by policymakers; the collaboration of energy companies and their innovativeness level, however, can only be enabled through grants (IEA, 2019). Another example of an indirect contribution to innovation is investments in infrastructure. A functional, reliable infrastructure nurtures innovation, but it cannot directly influence the happening or outcome of energy innovation (OECD, 2015b).

Nevertheless, the dataset shows that for policies to yield tangible outcomes, their impacts must be measurable. In addition, for improved decision-making and investment planning by energy companies, policies must be dependable and robust in case of governmental changes (Blazejczak and Edler, 2000).

4.1.2. Growth opportunities

Twenty-seven per cent of the dataset address growth as a motivator for innovation. It is argued that innovation will lead to price and performance improvements, for instance through economies of scale, which can create growth opportunities (Geels, 2018; Hojnik and Ruzzier, 2016).

Besides price and performance improvements, de Jesus et al. (2018) highlight that innovations around emissions reduction and a sustainable future create the chance for fresh and new business opportunities. Building on that, De Medeiros et al. (2014) add that innovations around emissions savings and sustainability are interconnected with the development costs of the required technologies and the LCOE.

4.1.3. Commitment to sustainability

Twenty per cent of the dataset outline the importance of sustainability as a driver of innovation. For example, de Jesus et al. (2018) highlight that climate change is becoming part of energy consumers' awareness and concern, also because NGOs are pushing for greater sustainability (Rauter et al., 2019). In addition, Brown et al. (2019) emphasise the influence of the Paris Agreement 2015 and the demand from governments on the uptake of innovations in the energy sector, especially in the electrification of heating and mobility. A study by Loredo et al. (2019) argues that "[…] established energy companies declaring that sustainability goals are relevant or highly relevant tend to be more innovative" (p. 10).

4.1.4. Competition

In 8 % of the dataset, competition is portrayed as a driver of innovation. For example, Hojnik and Ruzzier (2016) suggest that competing energy companies stimulate each other to innovate and that the innovation activity of the first energy company will encourage the competing company to imitate the first one's activity. Leitner et al. (2010) build on this argument by adding that energy companies can create a competitive advantage even if they just innovate themselves. Rauter et al. (2019) highlight the importance of adjusting leadership style and practice accordingly to be successful. Additionally, Helms (2016) positively links competitive pressures to improvements in the performance of companies. Also, "new entrants or incumbents from other sectors are more likely to drive radical innovation than traditional incumbents. Their success may lead to 'innovation races' when other firms follow a 'first mover'" (Geels et al., 2017, p. 467).

4.1.5. Cultural mindset

While competition focuses on a company's external perspective, the cultural mindset of a company focuses on the inside perspective. According to De Medeiros et al. (2014), openness to innovation and embedding innovation into processes of an organisation are strong facilitators of a flexible and proactive organisational culture, and high levels of internal and effective green innovation hinge on strong internal and external integration capabilities. This aligns with 8 % of the dataset, which view a *cultural mindset* as vital for a company's ability to probe potential opportunities and to investigate new paths. There also appears to be an accumulation principle where "innovation breeds innovation" (Baumol, 2002, p. 284), i.e. a company active in innovation is more likely to innovate and fund R&D activities (Hojnik and Ruzzier, 2016).

4.1.6. Rising energy prices

Rising energy prices may prompt customers to save energy and investigate alternative electricity sources, potentially increasing the demand for innovation (van den Bergh, 2013). However, this mechanism is reported only once in the dataset (2 %) and should therefore be interpreted as an exploratory finding rather than a general pattern in the literature.

4.2. Barriers to innovation

Forty per cent of the dataset discuss challenges hindering innovation. The following barriers can occur in different stages of the innovation lifecycle and are not explicitly linked to one innovation type. The EFFI revealed five barriers to innovation that are either common across energy companies or rooted in the market and regulatory frameworks.

4.2.1. Profitability and commercialisation

One-fifth of the dataset categorise *profitability and commercialisation* as a barrier, making it the most referenced barrier to innovation in the energy sector. Notably, none of the studies referring to profitability provided numerical indicators such as investment costs, expected returns, or payback periods; in the EFFI dataset, profitability is described exclusively in conceptual rather than quantitative terms.

Its hindering effect stems from the high profitability of the existing product portfolio and business model compared to the expected revenue from an innovation (Richter, 2013a). Asset-heavy energy companies, in particular, utilise their infrastructure enormously so that the costs per unit of energy served by centralised generation are relatively low. This leads to the current situation where they generate significantly more value from the existing business model and product portfolio than from the revenue expected from innovation (Tayal, 2017). Richter (2013b) and Chesbrough (2010) highlight that energy companies are reluctant to change how they earn money.

Additionally, operating decentralised assets efficiently would require a shift in operations (Tayal, 2017). Thus, according to Richter (2013a), innovative business models such as operating decentralised assets, e.g. wind parks, whose economic principles, value proposition and know-how resemble the utility business model and are closer to the current energy companies' role in the market, are more likely to be adopted. He points out that the value proposition of both business models to produce and sell power remains the same. At the same time, the organisational set-up only needs to be adjusted slightly, as the business case is very close and the customer relationship remains nearly the same. In comparison, business models that require a different company set-up, skill set or income-generation method, e.g. software sales, challenge established energy companies on multiple levels. However, their concern towards these very different business models does not

originate from using new technologies; it rather originates from the belief that they are not in a position to scale and commercialise new ideas because of a lack of expertise and skill set and new-to-be-established customer relationships in these areas (Chesbrough, 2010; Richter, 2013a).

Some scholars note that applying disruptive technologies especially requires business model innovation (Hansen et al., 2009). Similarly, Tröndle et al. (2019), using the example of end-customer autarky, describe it as a threat to the business model of established energy companies, as it makes some of their offerings, such as energy provision, obsolete. In addition, during the commercialisation period, innovations often need to be supported with grants to be attractive and affordable for customers, creating a dependency for the energy company on governmental support (Naber et al., 2017). Finally, Eklund and Kapoor (2019) describe navigating this nascent period of operating the old business model and generating revenue while transforming the organisation into a new model as a complex problem (or process), primarily because of the uncertainty of when the new business model will take over and become financially viable.

In contrast to the aforementioned challenges associated with the commercialisation of innovation, Apergis and Sorros (2014) observed that companies with high R&D expenditures and patent registrations tend to be more profitable.

4.2.2. Adverse effects of policy and regulation

The adverse effects of policy and regulation have been referenced in 17 % of the dataset as a barrier to innovation. The energy sector is firmly regulated because energy needs to be affordable for everyone in society, and the industry is guided by the principle of security of supply (EU Commission, 2007). In addition, energy transmission and distribution are natural monopolies (Faerber et al., 2018). Hence, regulation strongly affects operational and business models, as well as market structure, and shapes vertical integration, ownership relations, and, in the grid area, entry conditions. Consequently, regulation impacts the revenues of energy companies and their willingness to innovate (Deloitte, 2017; Marino et al., 2019). Even if energy companies solve technological challenges, regulation often challenges the scaling of innovation (Naber et al., 2017).

4.2.3. Lack of knowledge and skill set

Ideas are generated, realised within the innovation process and, in the best-case scenario, turned into a profitable business model. For this, it is crucial to have the proper skill set, knowledge of how to achieve it, and the capacity within the company to facilitate the necessary processes without compromising the speed of innovation (van den Bergh, 2013). Chesbrough (2010) identified the dilemma that many energy companies are still hung up on the concept of vertical integration to innovate, and that innovation ideas should emerge from within the company itself. He advocates for energy companies to rethink their innovation strategy and consider open innovation models.

Particularly regarding customer-side generation, the required skill set to operate new technologies and economic models calls for advancement. The economies of scale perspective, grounded in a central generation model, focusing on low prices, cannot be applied to customer generation models in which the price of the commodity energy is zero (Richter, 2013a).

For technological innovation, research (e.g., Acemoglu et al., 2012) found that funding for a cleaner energy market reallocated resources from dirty technologies rather than raising additional funds, resulting in declining investment in them. In the dataset, 16 % viewed the lack of knowledge and skill set as a barrier to innovation.

4.2.4. Misaligned company dynamics

Seventeen per cent of the dataset describe that managers and employees of energy companies restrict themselves from interacting with innovation. One possible explanation for this could be that "cognitive barriers restrict new ideas that do not fit with the firm's current business model" (Richter, 2013a, p. 1235). Furthermore, capital-intensive infrastructure, long asset lifecycles and natural monopolies characterise the energy industry, shaping routines and standards that are no longer questioned (Fagerberg, 2018b). Consequently, innovations that do not meet these routine-shaped standards are limited from being deployed or developed within the organisation and are often rejected, even if it is questionable whether the standards should have been applied to innovation in the first place (Sovacool, 2016). This kind of handling of innovation has become an accepted practice within the industry (Fagerberg, 2018a, 2018b). However, sometimes standards are absent but would be necessary to establish, especially if the method of an innovation is radically new (Sovacool and Griffiths, 2020). Hence, innovations that are not an improvement to an already existing product but are radically new take longer to be picked up from the energy industry if picked up at all (Geels, 2011, 2018; Mylan et al., 2015).

4.2.5. Risk-averse investments

Eleven per cent of the dataset categorise *risk-averse investments* as a barrier to innovation in the energy sector. Time and money are requirements for innovation (van den Bergh, 2013). Jamasb and Pollitt (2015) note a negative correlation between R&D expenditure and market liberalisation. They also highlight that energy grid companies are in a favourable position to innovate because their position entails fewer risks, as they are a natural monopoly, i.e. they face no competitors in the market for customers.

However, energy companies only start developing an investment interest in innovation once a market has been successfully created and demand for it has been proven, both reducing the investment risk (Deloitte, 2017). Yet, at that point in time, it is more costly for energy companies to enter these new markets to gain significant market share. On the other hand, securing a position in long-existing, established markets is even more costly.

A challenge for investments in high-risk innovations arises from a low level of innovation activity, as energy companies experienced in innovation are more likely to invest in innovative projects with a higher risk profile (Franc-Dabrowska et al., 2021). Gaddy et al. (2017) highlight the importance of venture capitalists investing in high-risk energy innovations, particularly in the early stages of innovation, to keep research running through the cash-intensive development phase and thereby avoid the *valley of death* (Weyant, 2011).

Investments focusing on green products and services in the energy sector are more likely to be considered public, and the consumer's willingness to pay for such products is low. Consequently, the return on investment is lower than from investments in comparable projects without sustainable aspects (Marin, 2014; Stucki et al., 2018), thereby elevating its risk profile.

5. Discussion

Based on a structured literature review, Section 4 provided the synthesised innovation drivers and barriers in the energy sector. However, their relationship has been overlooked by research. Rather than being reviewed in isolation, these innovation drivers and barriers can be better understood as interrelated. They represent four domains illustrated in Fig. 7. *Profitability and commercialisation* and *risk-averse investments* are barriers that interact with growth opportunities, which is noted as a driver. Consequently, these three factors are grouped under 'the importance of economic performance and value creation of innovation (2)'. *Policy and regulation* is noted as both a driver and a barrier, yielding a 'dual role (3)' for innovation. *Profitability and commercialisation* and *risk-averse investments* are also associated with 'the curse of incumbency on innovation (1)' alongside the driver *cultural mindset* and the barriers *misaligned company dynamics*, *lack of knowledge and skill set.* 'The effects of market dynamics on innovation (4)' forms the last group focusing on the external influence of the market on innovation in the

energy sector, which combines the drivers *commitment to sustainability*, *competition*, and *rising energy prices*.

Domains (1) and (2) can be directly influenced by energy companies. Instead, policymakers have a strong lever on the domains (3) and (4). These four domains structure the subsequent discussion, followed by a final subsection offering recommendations for future research.

5.1. The curse of incumbency on innovation in the energy sector

The findings of this review point to a pattern of structural and cultural constraints that collectively form a "curse of incumbency" in established energy companies. Decades of operating in monopoly-like market structures have entrenched long decision cycles and inward-looking routines that slow or discourage innovation. This aligns with research showing that incumbents may even resist or delay new technologies that challenge their established practices (Sovacool, 2016; Wainstein and Bumpus, 2016). Even when companies recognise the need for innovation, they often struggle to deploy it effectively, as industry analyses demonstrate (Deloitte, 2017). The analysis of the literature suggests that incumbency-related barriers stem from three interacting mechanisms. First, a persistent technology- and cost-driven mindset means that customer-, service-, or process-oriented innovations receive less attention or legitimacy (Helms, 2016). Second, organisational structures and routines create poor "fit" for novel activities innovations frequently clash with existing hierarchies, standards, and decision processes, as highlighted by de Medeiros et al. (2014). Third, lock-in effects—whether vendor dependencies, long-term asset commitments, or legacy IT systems—deeply restrict the room for change and limit collaboration with new entrants (Geels, 2018; Gjørtler Elkjær et al., 2021). A further barrier relates to capabilities. Innovation in emerging areas often requires skills that incumbents lack, making recruitment both time-consuming and risky. As Richter (2013a) notes, managers responsible for hiring exercise disproportionate influence over whether innovation capacity can be built in time. The long-term nature of these decisions reinforces uncertainty about whether upcoming innovations will become viable (Bain & Company, 2022).

Finally, although newer companies such as Octopus Energy demonstrate that more agile, customer-responsive models are possible even in the energy sector, it remains to be seen whether such firms can sustain this responsiveness as they grow and avoid the structural lock-ins that hinder incumbents.

Taken together, these findings show that incumbency in the energy sector is not driven by a single barrier, but by a combination of cultural inertia, process rigidities, capability gaps, and system lock-ins.

5.2. The importance of economic performance and value creation of innovation in the energy sector

Energy utilities that develop innovations—e.g., energy management systems for prosumers—cater to unmet needs for a reliable, efficient, and sustainable energy supply, thereby growing their businesses. Thereby, they enable their penetration into new geographic regions, demographics, or industries and can create new revenue streams (Botelho et al., 2021; Christensen et al., 2016; Pohlmann, 2019; Schmid et al., 2016). Yet, an energy utility's patience to innovate only sustains if it does not harm the current business model or cannibalise its current customer structure (Helms, 2016). In such a situation of old and new business models coexisting in parallel (Richter, 2013a), most energy companies' revenue expectations from new, innovative business models are benchmarked against high revenues from the old business model, which, at that point in time, has lower investment costs. In contrast, new business models often require high initial investments and additional funding to establish the necessary infrastructure, such as hiring new personnel or acquiring new equipment, while simultaneously failing to meet market demand.

This reluctance towards commercially uncertain business models is further reinforced by broader sector-wide financial dynamics. A notable finding of the EFFI review is that studies frequently frame profitability as a barrier to innovation, yet they provide limited numerical evidence on the financial profile of innovation investments themselves. This scarcity is consistent with broader observations that innovation expenditures in the energy sector are rarely disclosed at a granular level (IEA, 2025). Available sector-wide indicators nevertheless illustrate underlying economic constraints: R&D and innovation spending in the utility sector remains low relative to other technology-intensive industries, and publicly reported figures are sparse, making systematic comparisons difficult. Empirical research on innovation processes also highlights high commercialisation risks, long development cycles (often 7–15 years), and substantial failure rates for new products and services (Nemet, 2019; Popp, 2019), which together reduce the attractiveness of innovation for incumbents with established, high-margin business models. These broader patterns help explain why profitability appears consistently as a barrier in the literature, despite the limited availability of precise financial data within individual studies.

Beyond that, Jamasb and Pollitt (2015) suggest that market liberalisation has, contrary to expectations, reduced R&D expenditure in energy companies, thereby reinforcing existing resource constraints for innovation. The findings also indicate that demand for many new solutions must first be created, which implies that emerging business models are likely to generate negative or only marginal revenues in their initial years. Even when they succeed, their financial contribution tends to remain small relative to incumbent business lines. Moreover, innovation efforts in the energy sector are often linked to sustainable products for which customer willingness to pay is low (Stucki et al., 2018), further weakening the revenue case for early-stage innovation.

5.3. The dual role of regulation and policy for innovation in the energy sector

Affordability is also a core concern for regulators and policymakers. *Regulation and policy* appeared in the dataset as both driver and barrier, reflecting its dual role in innovation. Sixty-three per cent of the dataset consider them beneficial for innovation. This aligns with Christensen (1997), who argues that they can stimulate innovation and support new technologies or counter declining innovation activities (Stucki et al., 2018).

On the other hand, 17 % of the dataset argue that policy and regulation have adverse effects. They repel innovations and deter companies from entering the market because their nature is to maintain a stable status quo, leading to adverse effects (OECD, 2015a). When policy and regulation only consider existing business models of energy companies, they neglect new ones that may emerge due to technology or process innovation or new models are restricted because their roles are not yet defined in the current market set-up (EU Commission, 2018).

Moreover, policy and regulation are typically implemented for the long term, and there are no methods for ad hoc intervention or balancing short-term developments. Additionally, regulators tend to react slowly to new trends or technologies (OECD/IEA, 2017). The combination of slow reaction to changes and long-term projection of policy and regulation hinders innovation from scaling in the market (Naber et al., 2017). On top of that, policy and regulation can also lead to wrong incentives, such as incentivising long-term commitments or promoting business models based on subsidiaries rather than market principles.

5.4. The effects of market dynamics on innovation in the energy sector

Energy market liberalisation fundamentally reshaped market structures by introducing competition and price pressures. The expanding field of competitors, the emergence of prosumers, heightened customer price sensitivity, and declining LCOE for wind, solar, and hydrogen have all intensified competitive dynamics (Pezzutto et al., 2018). Yet, competition appears only marginally in the dataset, with just 8 % of

studies identifying it as a driver of innovation. Interestingly, high energy prices are mentioned only once, despite affordability forming alongside security of supply and sustainability (Galeano Galvan et al., 2020) the core "energy triangle" guiding the sector. While high prices are undesirable from a societal perspective (Kilian and Zhou, 2023), they can stimulate energy saving and interest in alternative supply options, thereby encouraging innovation (van den Bergh, 2013). The limited attention to this mechanism may reflect the complexity of market responses: rising prices may initially reduce consumption, which, in turn, lowers prices and can trigger a rebound in demand (van den Bergh, 2013). Moreover, expectations of future price declines can prompt accelerated fossil fuel extraction, moderating price effects (Sinn, 2012). These dynamics illustrate how price signals alone can destabilise the energy triangle. Van den Bergh (2013) therefore argues that energy-saving innovation must be paired with supportive regulation, such as emissions pricing, to counter these rebound effects. This reinforces the broader conclusion of our review: innovation in the energy sector is closely shaped by regulation and policy frameworks, which determine whether market signals translate into sustained innovation incentives.

5.5. Limitations and future research

While the EFFI framework was rigorously developed through a systematic analysis of literature, it has not yet undergone external empirical validation through expert interviews, case studies, or real-world applications. This constitutes a limitation, as the absence of external triangulation may constrain the generalizability and external reliability of the proposed categorisation. The framework should therefore be interpreted as a theoretically grounded, literature-derived model rather than a fully validated analytical instrument.

Despite this limitation, the development of the EFFI represents an important and necessary first step toward advancing conceptual clarity in this field. Literature-based frameworks play a well-established role in early-stage theory building, particularly in research domains that lack a coherent structure. The EFFI provides a transparent and replicable categorisation logic that enables a systematic examination of the drivers and barriers to innovation. Its primary contribution lies in offering an integrative structure that can guide and inform future empirical investigation, rather than substituting for it.

To ensure reliability within these boundaries, the framework was constructed using explicit coding rules, transparent inclusion criteria, and a systematic analytical procedure. This methodological rigour supports internal consistency and reproducibility even in the absence of external validation. Future research should extend this work by empirically testing the EFFI categories with practitioners and in case-based settings to more fully establish its external validity.

Also, the synthesised drivers and barriers to innovation are based on the current body of literature (Fig. 2) and their frequency (Figs. 5 and 6). A methodological limitation of this analysis is the implicit equal-weight assumption embedded in the frequency-based synthesis. By counting each driver or barrier once per study, the analysis assumes that factors mentioned more often are more prominent, even though frequency does not necessarily equate to empirical significance or systemic influence (Gough et al., 2012). This limitation is inherent to literature reviews that synthesise findings across heterogeneous study designs, where direct comparison of effect sizes or empirical strength is not feasible (Boell and Cecez-Kecmanovic, 2015; Paré et al., 2015). Nonetheless, frequency-based coding remains a widely accepted technique for identifying patterns and constructing conceptual frameworks from dispersed evidence (Snyder, 2019; Tranfield et al., 2003). As with most conceptually derived frameworks, an empirical validation of the categories represents a logical and necessary next step to establish their robustness and practical relevance (Jaakkola, 2020).

A further limitation concerns the heterogeneous granularity of driver and barrier categories, which reflects variation in how factors are discussed in the literature. While this affects direct comparability of frequencies, it preserves conceptual transparency and is consistent with established practice in literature-driven syntheses (Hoon, 2013). Also, *rising energy prices* were referenced only once in the dataset and should therefore be interpreted as exploratory rather than generalisable.

Moreover, the reviewed studies provide little quantified evidence on the financial performance of innovation investments, meaning that profitability appears primarily as a conceptual rather than numerically supported barrier; future empirical research should address this gap.

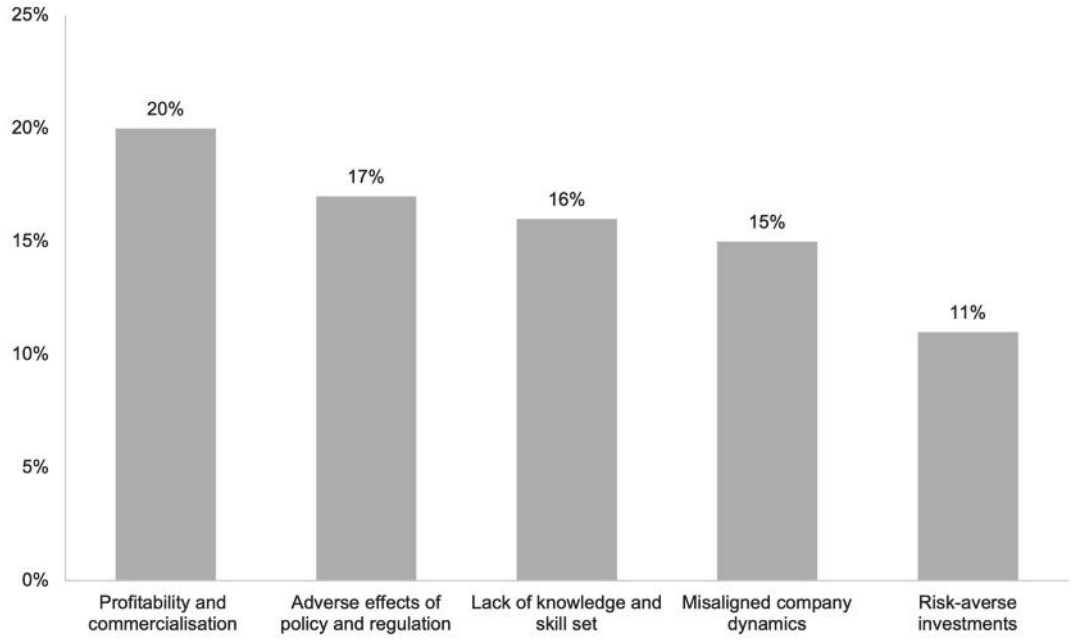

Fig. 6. Percentage of papers in the dataset that report each innovation barrier
Note: Each barrier was analysed independently to account for its individual frequency in the dataset.

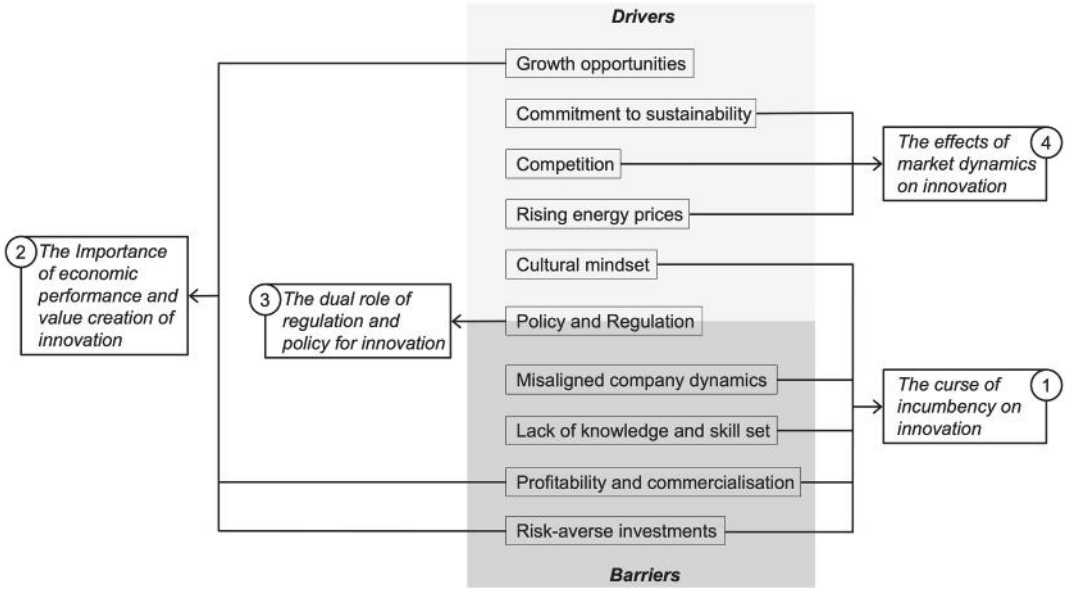

Fig. 7. Domains of innovation drivers and barriers in the energy sector.

6. Conclusion and policy implications

The study investigated the drivers and barriers to innovation by analysing a structured literature dataset using the Energy Framework for Innovation (EFFI). It made several contributions: it illustrated the energy, data, and monetary flows across the European electricity sector (Fig. 1), synthesised the drivers and barriers to innovation (Fig. 4) and developed four overarching domains in which these factors intersect (Fig. 7): (1) the curse of incumbency, (2) the importance of economic performance and value creation, (3) the dual role of regulation and policy, and (4) the effects of market dynamics. Domains (1) and (2) are primarily shaped by company-level behaviour, while domains (3) and (4) are predominantly influenced by policymakers and regulators. The analysis also revealed an imbalance in the literature, with substantially more attention directed at innovation drivers than barriers. While all studies in the dataset identified at least one driver of innovation, only 40 % also referenced a barrier. Moreover, the frequency of barriers was relatively even (11–20 %), whereas the frequency of drivers ranged widely from 2 % to 63 %.

The synthesised barriers profitability and commercialisation challenges, adverse regulatory effects, capability gaps, misaligned organisational dynamics, and risk-averse investment behaviour highlight the structural obstacles facing established energy companies. In contrast, the most frequently cited drivers—beneficial policy effects, new market opportunities, sustainability commitments, competitive pressures, internal culture, and rising energy prices tend to reflect ideal or externally created conditions rather than company-internal levers. This imbalance produces an optimistic narrative that underplays the concrete organisational, economic, and structural constraints described in the discussion.

The findings indicate that energy companies face difficulties in balancing investment between well-established business models and emerging innovations, especially given the long period required for innovations to become financially viable. High upfront investment costs, higher risk profiles, and lower expected revenues relative to existing business lines reinforce this trade-off. For established energy companies, exploring blue ocean strategies (W. Kim and Mauborgne, 2005) may provide one avenue to escape the "valley of death" that many early-stage innovations face. Yet, such strategies require skills, organisational flexibility, and openness to external collaboration—capabilities that many incumbent firms still lack. The literature shows that business-as-usual attitudes, internal process rigidities, and legacy systems limit the potential for transformative innovation. Approaches such as open innovation (Chesbrough, 2003), strategic partnerships with firms outside the energy sector and targeted early-stage incentives could help firms broaden their innovation activities, integrate external knowledge, and better navigate the inherent uncertainty of innovation processes.

However, the discussion across Sections 5.1–5.4 makes clear that advancing along only selected drivers or barriers will not be sufficient to accelerate innovation in the energy sector. Many of the most persistent obstacles, such as incumbency effects, high capital intensity, regulatory uncertainty, legacy lock-ins, and volatile price signals, are systemic rather than firm-specific. While companies can influence internal factors such as culture, skills and processes, they cannot independently resolve the structural, economic, and regulatory constraints that shape innovation outcomes. This creates a strong rationale for policy intervention: because the barriers are structural, the enabling conditions for innovation must also be structural.

To make this connection explicit, Table 2 summarises how the insights from Sections 5.1–5.4 translate into the corresponding policy implications derived below.

Based on the analysis of the literature, several policy implications emerge. First, policymakers should reduce regulatory uncertainty by providing predictable, multi-year frameworks for grid access, permitting, market design and participation rules. Such stability is particularly important for long-payback innovations that require upfront investment despite volatile market conditions.

Second, innovation policy should incorporate targeted risk-sharing mechanisms. Early-stage innovations often face high capital intensity and uncertain revenue streams; instruments such as innovation grants, loan guarantees, public procurement for demonstration projects, or regulatory sandboxes can lower the threshold for experimentation and support the commercialisation of new business models.

Third, structural lock-ins—including legacy infrastructure, long-term contracts and rigid technical standards—require deliberate policy attention. Incentives for interoperability, upgrades to ageing systems and frameworks that promote cross-sector collaboration can help overcome organisational inertia and allow incumbents to integrate external knowledge more effectively.

Finally, because market volatility alone does not reliably generate sustained innovation incentives, policy design should ensure that price

Table 2
Policy implications.

Discussion Section	Key Mechanisms identified	Corresponding Policy Implications	Sources
5.1 The curse of incumbency on innovation in the energy sector	Legacy lock-ins, organisational rigidity	Policy support to overcome structural lock-ins	Geels (2018) on lock-in mechanisms; Gjørtler Elkjær et al. (2021) on legacy systems and vendor ties
5.2 The importance of economic performance and value creation of innovation in the energy sector	High costs, long payback, uncertain revenue	Regulatory certainty + risk-sharing instruments	Stucki et al. (2018) on low willingness to pay; Jamasb and Pollitt (2015) on reduced R&D and resource constraints
5.3 The dual role of regulation and policy for innovation in the energy sector	Regulation as both enabler and barrier	Predictable, innovation-oriented regulation	Sovacool (2016); Deloitte (2017) on inconsistent regulatory signals; Tayal (2017) on barriers from outdated frameworks
5.4 The effects of market dynamics on innovation in the energy sector	Volatile price signals, rebound effects	Align price signals with long-term decarbonisation (e.g., carbon pricing + support for energy-saving technologies)	van den Bergh (2013) on rebound effects; Sinn (2012) on fossil-extraction response to price expectations

signals align with long-term decarbonisation objectives. The integration of emission pricing with measures supporting energy-saving and low-carbon technologies can help stabilise investment expectations and enable systemic transformation. Together, these implications outline where policy intervention is most effective and how structural conditions can be shaped to support innovation in the energy sector.

CRediT authorship contribution statement

Laura Antonia Faerber: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Nazmiye Balta-Ozkan:** Writing – review & editing, Supervision. **Enes Ünal:** Writing – review & editing, Supervision.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Laura Antonia Faerber reports a relationship with E.ON SE that includes: employment and equity or stocks. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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2026-02-01
Elsevier
https://doi.org/10.1016/j.enpol.2025.115002
Faerber LA, Balta-Ozkan N, Ünal E. (2026) Synthesised innovation drivers and barriers in the energy sector. Energy Policy, Volume 209, Part B, February 2026, Article number 115002

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