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Regulation, Innovation, and Systems Integration: Evidence from the EU

Carlo Cambini [1,*], Raffaele Congiu [1] and Golnoush Soroush [2]

[1] Department of Management, Politecnico di Torino, 10129 Turin, Italy; raffaele.congiu@polito.it
[2] Florence School of Regulation, European University Institute, 50133 Florence, Italy; golnoush.soroush@eui.eu
* Correspondence: carlo.cambini@polito.it

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Abstract: Energy systems integration (ESI) provides a holistic view of the electricity, gas, and heat sectors, which allows the identification and delivery of system solutions that lead to an overall cost efficiency while granting the reliability of the energy system. In this paper, we search for evidence of investments in ESI in the EU to assess whether policymakers are incentivizing its adoption adequately. To do so, we examine how innovation is being fostered in the energy sector in six EU countries by looking at the incentives provided by each country's regulatory system. We look for evidence on investments in ESI-enabling technologies or ESI projects. We find a variety of approaches towards incentivizing innovation, which range from regulation-driven to government-driven ones. Preferences for different technologies emerge on a per-country basis. Nevertheless, what appears as most striking is the low level of investments throughout the six countries, both for ESI-enabling technologies and ESI projects. Although ESI's role in the EU's green transition has been recognized, there is still a need for technological and policy solutions to foster its adoption.

Keywords: energy systems integration; sector coupling; regulation; innovation; research and development

1. Introduction

In December 2019, the European Commission signed the European Green Deal, where it committed to the goal of becoming the first climate-neutral continent by the year 2050 [1]. Within such an ambitious plan, the decarbonization of the energy sector has an important role to play [2]. Technological progress in the field of generation from renewable energy sources (RES) and distributed generation (DG) has provided an alternative to fossil-fuel based energy generation in the electricity sector. Nevertheless, integrating these technologies comes with its own set of problems. The first one is the intermittent nature of these energy sources, which do not allow matching generation to demand since they depend on external factors that cannot be controlled or are hard to predict [3]. This requires installing traditional backup generation capacity to be used when RES generation is low. On the other hand, this leads to curtailment when peaks of production occur so that generation exceeds demand. The second problem is the additional complexity added to the grid by the high number of DG connections and the bilateral flows of energy, which can cause extra network costs for distribution system operators (DSOs) [4]. This requires not only investments in interconnections and in strengthening the distribution grid but also the introduction of novel tariff mechanisms that consider these additional costs [5,6]. Thus, although decarbonizing the energy sector is technologically possible, it is a complex endeavor which requires substantial investments.

ESI helps achieve a cost-efficient solution [7]. ESI—or sector coupling—is an approach that looks broadly at the electricity, gas, and heat sectors in order to exploit synergies between the systems that can lead to a more reliable, clean, and affordable energy system [8]. Through a holistic view, ESI identifies solutions that can provide a benefit to the whole system, rather than the single network firm [9]. ESI is enabled by flexibility providing technologies, such as energy storage systems (e.g., electric batteries), conversion systems (e.g., hybrid heat pumps, cogeneration, power-to-gas), smart grids (SG), and demand response (DR) programs [10]. These technologies address the downsides of RES generation: storage and conversion systems decouple generation and consumption; DR allows smoothing the demand curve; SG permits increasing coordination between grid users [11]. However, technologies are not sufficient to drive the integration of the energy systems. ESI requires policies that incentivize the adoption of these technologies, that foster coordination between grid users, and that require network firms to draw coordinated development plans across the energy system. For a more detailed discussion on ESI, we refer to [12,13].

The role of ESI for the future of the EU energy sector is highlighted by the recent Ten-Year Network Development Plan, a joint report by the European Network of Transmission System Operators for Electricity (ENTSO-E) and the European Network of Transmission System Operators for Gas (ENTSOG) [14]. In this report, ENTSO-E and ENTSOG worked together to develop scenarios that will guide the decision on infrastructure investment to enhance the integration of the European energy market. ESI plays a role in these scenarios, as the report stresses the importance of conversion technologies and of the interaction between the electricity and gas systems.

The relevance of the topic is captured by the attention it has received in the scientific literature, which, however, only focused on its technological aspects. To the best of our knowledge, the economic and policy dimensions were analyzed only in [12,13]. While [12] discusses the economics of ESI, in [13] the authors focus on the barriers to its adoption and on providing policy solutions to overcome these barriers. This paper contributes to the literature by presenting a snapshot of six EU countries' regulatory frameworks and their investments in energy integration. The aim is to link how regulators are incentivizing innovation in the energy sector with investments in ESI or ESI-enabling technologies. The value our contribution is threefold: first, we put together the insights from the literature on the interplay between regulation and innovation; second, we show how regulators of different EU states are addressing this issue; third, we report on current investments as a way to assess the effectiveness of the adopted solutions. Such analysis is qualitative in nature, as the novelty of the topic and of the policies does not lend itself to ex-post assessment. However, this initial evaluation can provide policymakers with guidance to understand whether current incentives are likely to be sufficient or if there is a need to intervene more strongly.

We find that, while incentive mechanisms strongly differ from one country to the other, all six countries show low levels of investments in ESI. From a policy perspective, this therefore calls for a more thorough revision of the regulatory framework in Europe, should policymakers want to support the development of ESI-enabling technologies or projects.

The rest of the paper is as follows. Section 2 discusses traditional and recent types of regulation, focusing on how they incentivize innovation. Section 3 provides an overview of regulatory frameworks and their incentives for innovation from a selection of six EU countries while reporting on their level of investment in ESI. Section 4 discusses the results and the limitations of the study. Section 5 provides conclusions.

2. Regulatory Instruments: Insights from the Economic Literature

The energy transmission and distribution networks are natural monopolies: that is, the industry structure is such that a single firm can produce any level of output at a lower cost than the case in which it was produced by two or more firms [15]. In these cases, rather than encouraging competition, it is more efficient to have a monopolist subject to regulation along some or all the dimensions of price, quality, output, and network access [16]. How regulatory policies are designed can greatly affect their effectiveness, especially when it comes to influencing firms' decisions regarding investments in infrastructure and innovation [17–19]. In this section, we review the different types of regulations adopted in the energy sector, discussing their impact on investments and innovation by drawing on the insights provided by recent economic literature.

2.1. Controlling the Price

When controlling the price, the regulator needs to find an equilibrium between protecting consumers from monopoly pricing and granting investors an adequate return to maintain and expand the infrastructure. Price control defines a period during which a national regulator sets the prices the utility is allowed to charge (or the rules to define them).

A first way to achieve this is through rate of return regulation. Under this scheme, the utility is subject to a cost-plus mechanism, that is, the regulator sets prices so that they cover the firm's costs and grant an extra return that pushes the utility to continue investing. While this type of regulation has the merit of strongly enhancing investments in infrastructure, it also provides an incentive to over-invest in capital equipment. This phenomenon is called "gold plating" and may lead to excessive investment expenses and therefore to inefficient use of the resources [20]. However, over-investment is a lesser problem compared with the absence of an incentive to operate efficiently, since, under rate of return, the utility will recover any costs it bears [16]. An alternative to rate of return regulation is price capping. Under this scheme, the regulator sets a series of prices for the utility for the length of the price control. This trajectory takes into account expected costs and is characterized by the presence of an efficiency target which yearly reduces the price the utility can charge. If the utility is able to incur lower costs than predicted, it will benefit from the cost savings. Otherwise, it will pay the extra costs. This makes price capping a form of incentive regulation. Price capping usually includes automatic adjustments to prices to take into account occurrences which the utility cannot control, such as inflation. The price cap set for the next price controls takes into account the utility profit levels, thus lowering (increasing) the base price if excessive profits (losses) are being made. Due to this, the length of the price control is critical in determining the strength of the incentive [21]. Closely related to price cap regulation is revenue cap regulation, where the regulator sets the overall revenue the firm can earn. This regulatory scheme can be used when the firm sells a variety of services since it leaves it with the ability to choose its prices, so long as the overall revenue does not exceed the cap [22].

Rather than using the firm's expected costs to set the price cap, the regulator can use the costs of similar firms as a benchmark. This approach is called yardstick competition. By comparing similar firms, the regulator can infer the utility's achievable costs, thus reducing the degree of information asymmetry between the firm and the regulator [23]. Yardstick competition can provide higher efficiency incentives than traditional price capping [24].

2.2. Efficient Investments

Although price capping solves the problem of rate of return regulation of not providing efficiency incentives, it comes with some drawbacks. Cost trajectories are made ex-ante based on estimations which get more unreliable as they look more into the future. This requires limiting the length of the regulatory period and indirectly introduces elements of cost-plus regulation, as the authority refers to incurred costs as a baseline during regulatory reviews [16]. The utility is thus incentivized to cut costs as early as possible during the regulatory period to benefit from all the cost savings, rather than consider the long term. This focus on the short-term can limit investments in infrastructure, which typically have a payback time which is longer than the regulatory period [21]. To overcome this problem, regulators generally have dealt with operating expenditures (Opex) and capital expenditures (Capex) differently [25]. Under the building block approach, allowed revenue is calculated as the sum of estimated Opex, depreciation, and return on capital. The latter represents the opportunity cost of investing in the network rather than in other activities. Therefore, while forecast Opex are added directly, Capex are capitalized in the regulatory asset base (RAB), a partial sum of the depreciated value of assets used by the firm. A rate of return is applied to the costs stored in the RAB: its measure is given by the weighted average cost of capital (WACC), a remuneration which takes into account the cost of both debt and equity. Although this is effective in incentivizing infrastructure investment, it can bring a bias towards Capex. To address this problem, the UK regulator Ofgem introduced the Totex approach [26]. Under this approach, a fixed share of the total cost (fast money) is fully expensed in the year in which it is expected to be incurred, while the rest (slow money) is added to the RAB.

2.3. Investment in Infrastructure

Infrastructure investment is strongly affected by the level of regulatory uncertainty. The authors of [27] identify three main elements that can lead to under-investment: the way costs are added to the RAB, the length of the regulatory period, and regulatory opportunism. The regulator can impose some scrutiny to determine which costs are added to the RAB to avoid imprudent investment decisions. This scrutiny should be made ex-ante to reflect the information the firm had at the time of the investment decision. Ex-post assessment may lead to cautious behaviors by the utility, favoring short-term, unambitious projects. The length of the regulatory period affects how much of the cost savings the utility is allowed to seize. Excessively short regulatory periods undermine the strength of the efficiency incentive. Regulatory opportunism can discourage firms from investing as it leads to concern that the return on capital can be reduced once the investment has been made.

2.4. A Focus on Outputs

Output regulation builds on the strength of price capping by broadening its scope from the price dimension to quality and output [28]. With a price cap, a way for a firm to reduce costs is to cut on service quality and other sustainable targets. To address this, the regulator sets output targets that the utility has to meet that reflect customer needs or an innovation stimulus. The utility is free to choose the best course of action to achieve them, as the regulator makes no prescription. This enhances efficiency by leveraging on the information asymmetry between firm and regulator. In fact, the firm is better positioned to know what is the most efficient way to provide an output (e.g., it has better information on costs). In defining its choice of actions, it needs to consider what is relevant to customers [29]. By clearly defining performance targets for given outputs and then linking firms' revenues to their achievement, output regulation shifts the perspective from firms' costs to user benefits. Output regulation introduces a trade-off, as meeting these targets can come at a higher cost than with a pure price cap. Additionally, as discussed by [30], properly implementing output regulation can be both challenging and costly for the regulator.

2.5. Investment in Innovation—Input- vs. Output-Based Incentives

Focusing on economic efficiency can reduce R&D and innovation investments, as they carry risks [31,32]. To promote them, the regulator can provide firms with specific incentives [33]. Following [34], we can categorize them as input- or output-based. Input-based approaches include R&D costs explicitly in the regulatory scheme. This can be done via direct pass-through to customers or through capitalization in the RAB. Capitalized R&D costs can also be subject to a higher return on capital rates or to adjusted depreciation times. Input-based methods share the disadvantage of shifting all the risk of R&D to customers, while firms are still able to benefit from it in case it generates cost efficiencies. Although input-based approaches provide a strong incentive to invest in R&D, no attention is given to whether this results in useful innovation. Output-based approaches do just that, rewarding firms only for successful innovations. A first method is to raise the price or revenue cap for a firm that introduced a useful innovation, granting extra revenues. This way, the additional revenue does not depend on cost sustained but on the value of the innovation. A second method is to extend the duration of the regulatory period, leaving more time for the company to benefit from the cost savings obtained by innovations. The main challenge of output-based approaches is for the regulator to appropriately recognize innovation outputs. A mix of input- and output-based incentives can be the optimal solution to properly balance the risk of innovation between customers and the firms: input-based incentives can be useful for very high-risk projects, while a shift to output-based incentives can occur for more mature and thus low-risk solutions.

3. Incentives to Innovation and Investments in ESI in the EU

After having examined what tools regulators have at their disposal to foster innovation, in this section, we look at how EU regulators are addressing the issue. We analyze the regulatory frameworks for electricity and gas network operators in the United Kingdom, Germany, France, Italy, Denmark, and the Netherlands. We focus on the innovation incentives provided by each regulatory scheme, thus focusing more on countries that offer more sophisticated incentives. The novelty of the ESI paradigm does not allow us to perform a quantitative analysis of the effect of such schemes on investments in ESI. However, by reporting on the integration projects being conducted in these countries by TSOs and DSOs, we provide some preliminary information on the effectiveness of each country's regulatory scheme in fostering investments in ESI or ESI-enabling projects.

The projects were categorized according to their technological domain, dividing them into smart grids, storage, conversion technologies (i.e., ESI-enabling technologies), and ESI. Where data allowed it, a more detailed categorization was used. For each country, we included in our examination every integration project on which we could find public data. Although we wished to focus on ESI projects, their limited number brought us to include also projects which do not strictly fall under the integration of networks but that are needed to enable ESI, such as storage and SG. For each country and technology domain, we list incentive mechanism, source of funding, total budget, and main stakeholders. This gives us information on both the investment level and the funding type for each category. Appendix A presents some examples of the integration projects being considered in the analysis.

3.1. United Kingdom

In 2010 the UK's Authority, Ofgem, introduced its new regulatory framework: RIIO, which stands for Revenue = Incentives + Innovation + Outputs. Under RIIO, which took effect in 2013, network companies are subjected to an 8-year regulatory period where the regulator establishes ex-ante the outputs that network operators must deliver and the revenues they are allowed to earn if efficient. This revenue cap is adjusted yearly through performance and innovation incentives [29].

Innovation is stimulated through a long regulatory period, the commitment not to change revenue allowances outside of the agreed mechanisms, an equalization of Opex and Capex, a focus on the delivery of outputs, and especially by time-limited innovation stimuli, one for the electricity and one for the gas network. Ofgem's decision to include innovation incentives in RIIO was strengthened by the results of an independent evaluation of the Low Carbon Network Fund [35]. The evaluation, commissioned by Ofgem in 2016, estimates net benefits between £800 million and £1.2 billion from the scheme once companies roll out their projects, with the potential for a six-fold increase in a scenario of a country-wide rollout [36]. Each innovation stimulus is comprised of three measures: the Network Innovation Allowance (NIA), the Network Innovation Competition (NIC), and the Innovation Roll-out Mechanism (IRM). The innovation stimuli were introduced in 2013 for electricity and gas transmission and gas distribution, and in 2015 for electricity distribution. The NIA is a yearly adjustment to the revenue allowance of network firms, which is used to finance small R&D and demonstration projects. This allowance is capped at 0.5%–1% of base revenues for each company, depending on the quality of its innovation strategy [37]. The approval of NIA projects follows their disclosure on a website designated by the authority, and no specific authorization by the regulator is required (each network licensee has to produce an annual report which summarizes its NIA activity [38,39]). Until 2017, the NIA provided about £61 m every year to network licensees [35]. The NIC is a competition through which few large development and demonstration projects run by TSOs and DSOs are selected for funding. Unlike the NIA, the NIC focuses on projects aimed at granting environmental benefits. For a project to be funded, the licensee must show how the innovation creates new knowledge and how it can be shared among network operators; the innovation must provide long-term value for money to network customers; and it has to help accelerate the move to a low carbon energy sector or grant environmental benefits [40,41]. Annually, up to £70 m for the electricity sector and £20 m for the gas sector can be awarded through the NIC [35]. These funds can cover up to 90% of the project budget, so that network licensees have to incur part of the cost. Third parties can provide external funding, and their participation is also incentivized through a web portal where ideas for NIC or NIA projects can be given to network licensees [40]. Network operators have an obligation to disclose data on NIC and NIA projects on the Smarter Networks portal to help disseminate knowledge [42].

IRM is an incentive that works by adjusting allowed revenues to fund the roll-out of trialed innovations if they have environmental benefits and provide value for money for consumers. However, the operator cannot get commercial benefits from this roll-out within the price control period to avoid financing investments that should be made under business as usual by the company [43].

While the RIIO model led to higher customer satisfaction and innovation spending, it also resulted in higher returns than anticipated for TSOs and DSOs [44]. Following a review of the framework's performance and consultations with industry stakeholders [41,45], the regulator has decided to modify RIIO for the next price control beginning in 2021. The changes and their rationale are described in Ofgem [44], among them:

(1) A shortening of the price control length from 8 to 5 years, as in the current regulatory period the high uncertainty in the energy sector generated unreliable assumptions and forecasts, which led to allowances being set too high and performance targets too low;
(2) An increase in innovation delivered through business as usual while keeping the innovation stimulus package. While the NIA was generally considered useful by stakeholders as it increases collaboration between network operators, some stakeholders pointed out a diminishing interest in the NIC. The IRM is also under scrutiny because a shorter price control period reduces its usefulness;
(3) An overall simplification of the price control, especially regarding how outputs and costs are set.

In order to provide an insight into the quantitative impact of this regulatory approach, we categorized—based on the technological domain—the projects that started within 2013 and September 2018 with a budget of over £1 million and which have been financed under NIA and NIC. The 118 projects make up for almost 75% of the overall NIA and NIC budgets. Five categories were used, with each project being assigned to a single group—the most relevant one—even in the case in which its scope would encompass more than one. We report the findings in Table 1.

Table 1. Classification of the UK's Network Innovation Competition (NIC) and Network Innovation Allowance (NIA) projects (above £1 million budget).

Category	No. Projects	Budget (£m)	Avg. Budget (£m)
Electric and hydrogen vehicles	5	11.0	2.2
Smart grids	13	65.5	5.0
Storage systems	2	2.9	1.4
Energy systems integration	1	5.2	5.2
Others	97	467.4	4.8
Total	118	552.1	4.7

Source: [13], elaboration on data available from the *Smarter Networks* portal.

Although the NIC and NIA have generated significant investments, only 16 projects fall under ESI related categories (by which we mean ESI and its enabling technologies: storage systems, conversion technologies, and ICT) for a total budget of £73.6 million (13% of the overall budget). Only one project deals directly with networks integration.

3.2. Germany

BNetzA, the federal Authority, sets caps on firms' revenues with a regulatory period that lasts 5 years. The allowed revenues are set ex-ante and then adjusted yearly based on factors that account for efficiency, quality, and expansion of the network [46]. Incentives to research and development and investments in new technologies in Germany are mainly undertaken under large funding programmes funded by the Federal Government to reflect the national energy policy [47], leaving the regulator with a lesser role in this regard. However, an incentive mechanism exists in the form of an adjustment to the revenue allowance: every year, network operators can partially recover R&D project expenses undertaken in that year as reported in the financial statements [46]. The increase in revenue allowance equals 50% of the total costs not covered by public funding. For a project to be eligible, it must be included in a research funding program approved by a regulatory authority or governmental body (e.g., the Federal Ministry for Economic Affairs and Energy). R&D costs already included in the initial revenue caps are not eligible for adjustment.

Table 2 presents an overview of the main recent network innovation projects and funding programmes in Germany.

Table 2. Overview of network innovation projects in Germany.

Project Category	Project	Incentive Mechanism	Source of Funding	Total Budget	Main Stakeholders
Smart grids	SINTEG	Grants	National funds (up to €230 million) and private funds	€600 million	TSO and DSO
Storage	*Energy Storage Funding Initiative*—R&D and demonstration of storage technologies	Grants and privately matched funds	National and private funds	€200 million	TSO, DSO, and consumers
	KfW Bank—loans for electric batteries (EBs)	Low-interest loans	Government-owned development bank	€80 million	Consumers
Conversion	CHP Act	Surcharge to electricity from CHP	Increase in network tariffs	Max annual fund of €1.5 billion	Generators

Source: Elaboration on data available from Appendix B.

3.3. France

The French Authority, the Commission de Régulation de l'Énergie (CRE), uses a revenue cap with a 4-year regulatory period. Each year's revenues are set ex-ante and mainly comprise an estimation of Opex and a return on the RAB. Opex and Capex are treated differently: while the firm shoulders deviations of operational expenditures from forecasted ones, any difference in capital expenditures is recovered in the following years through adjustments to the revenue allowance [48–51]. This constitutes a hybrid system in which Opex are subject to incentive regulation while Capex are subject to rate of return regulation, and can thus create incentive bias. This has been recognized by the regulator, which in [49] introduced a differentiation in the way grid and off-grid expenditures are treated, which however does not entirely resolve the problem. CRE also introduced a further differentiation between network and non-network expenses. While network expenditures are treated as before, for non-network expenditures Opex and Capex are subject to the same incentives.

At the beginning of the regulatory period, each network operator proposes an annual R&D budget that is subject to the approval of the sector regulator. Deviations from planned R&D expenditures are recovered entirely through adjustments to the revenue allowance in the following years. As a caveat, each year the network operator is required to submit a new report, which can then be audited by the authority, to justify discrepancy with respect to the planned budget.

Due to the different schemes applied to Opex and Capex, the regulator has observed that investments that produce a reduction in Capex (e.g., demand-side management, storage) and a less than proportional increase in Opex may be penalized [51]. This is especially true for smart grid investments, which for this reason are further incentivized: the regulator allows smart grid projects with Opex higher than €3 million to recover justified cost overruns through subsequent adjustments to the revenue cap.

Table 3 presents an overview of the major recent network innovation projects in France.

Table 3. Overview of network innovation projects in France.

Project Category	Project	Incentive Mechanism	Source of Funding	Total Budget	Main Stakeholders
Smart grids	SMILE, FlexGrid	Grants and adjustment to the revenue allowance	EU and national funds and increase in network tariffs	€640 million	TSO and DSO
	SG pilot projects	Grants and adjustment to the revenue allowance	National funds and increase in network tariffs	€192 million	TSO and DSO
Storage	11 pilot projects in isolated networks and RINGO project	Adjustment to the revenue allowance	Increase in network tariffs	€160 million	TSO and DSO
Conversion	Jupiter 1000 project	Grants	EU, national and private funds	€30 million	TSO

Source: Elaboration on data available from Appendix B.

3.4. Italy

The Italian Authority, the Autorità di Regolazione per Energia Reti e Ambiente (ARERA, previously AEEGSI), adopts an 8-year regulatory period for electricity transmission and distribution [52], a 6-year period for gas distribution, and a 4-year period for gas transmission [53,54]. The regulatory approach is similar to France's, with revenues being established ex-ante with a RAB-based approach, and with deviations from forecast expenses being treated differently according to whether they are operational (incentive regulation) or capital (cost of service).

To address the distortion that this may pose, the regulator intends to adopt a Totex approach starting from 2020 for both the electricity and gas sectors [55]. Under this approach, capital and operational expenditures are treated in the same way by the regulator. Incentives for implementing smart grid projects and for the adoption of battery storage systems are in the form of a 2% increase in the WACC for 12 years for innovative projects [56]. Table 4 presents an overview of the major recent network innovation projects in Italy.

Table 4. Overview of network innovation projects in Italy.

Project Category	Project	Incentive Mechanism	Source of Funding	Total Budget	Main Stakeholders
Smart grids—integration of DG	SG pilot projects	+2% WACC for 12 years	Increase in network tariffs	€17.4 million	DSOs
	e-Distribuzione—SG projects	Grants	National Operational Program (PON): EU + national funds	€180 million	DSO
2G smart meters	*e-Distribuzione*—Open Meter project	No incentive (mandatory)	Increase in metering tariffs	€3.9 billion	DSO
Conversion and storage systems	*Terna S.p.A.*—Project Lab and Large-Scale Energy Storage pilot projects	+2% WACC for 12 years	Increase in network tariffs	€253 million	TSO

Source: Elaboration on data available from Appendix B.

3.5. Denmark

Previously the Danish Energy Regulatory Authority (DERA) was responsible for the electricity, gas, and heating market. Since July 2018, the Danish Utility Authority (DUR), a single regulator for all public services, was introduced to ensure greater integration between sectors by proposing consistent and interconnected policies [57]. DSOs are subject to a revenue cap with the addition of a maximum rate of return on network assets, with a 5-year regulatory period for electricity and a 4-year period for gas [58]. Revenues are set annually based on the regulatory price, adjusted according to inflation and the expected demand volume in terms of kWh. The level of Capex to be remunerated is calculated through the RAB. The model is adjusted annually through benchmarking mechanisms that consider cost efficiency and supply quality. The regulator can increase the allowed revenue to incentivize certain types of investments. As for the TSO, Energinet—a wholly state-owned company—is the sole operator of both electricity and gas transmission networks. Energinet is not subjected to any efficiency requirements, but the regulator may assess the partial or total exclusion of specific costs that do not fit into efficient operation [59]. In addition, no incentives for quality of supply are provided. A revenue cap system with efficiency requirements could be introduced from 2021 [59].

Similar to Germany, incentives to R&D and demonstration projects come mainly from national funding programmes. Table 5 provides an overview of innovation projects which have been primarily financed by these programs.

Table 5. Overview of network innovation projects in Denmark.

Project Category	Project	Incentive Mechanism	Source of Funding	Total Budget	Main Stakeholders
Smart grids	EnergyLab Nordhavn, Ecogrid 2.0	Grants	EUDP programme [1]	DKK 226.53 million	TSO and DSO
	CITIES, FED	National Funds	Innovation Fund [2]	DKK 114.34 million	TSO and DSO
Storage	CORE	Grants	EUDP programme	DKK 12.53 million	TSO and DSO
Conversion (P2G)	BioCat	Public funding	ForskEL [3]	DKK 59.95 million	DSO
	Biocat Roslev, P2G-Biocat 3, EP2Gas	Grants	EUDP programme	DKK 37.16 million	TSO and DSO
	HyBalance	European and national funds	Horizon 2020 and EUDP programme	€15 million	TSO and DSO
Energy systems integration	SEMI, SMARTCE2H, Hybrid Energy Networks	Grants	EUDP programme	DKK 19 million	TSO and DSO
	EPIMES	National Funds	Innovation Fund	DKK 7 million	TSO and DSO
District heating	Greater Copenhagen DH system, FLEX-TES, LHCPB	Grants	EUDP programme	DKK 206.22 million	TSO and DSO
	HEAT 4.0	National funds	Innovation Fund	DKK 37.27 million	DSO

Source: Elaboration on data available from Appendix B. [1.] Energy Technology Development and Demonstration Program (EUDP) consists of an autonomous entity managed and owned by a board of directors directly elected by the Danish Ministry of Energy [60]. [2.] The Innovation Fund is a Danish organization set up to allocate funding to research and development projects in all sectors, not just energy [61]. [3.] ELForsk is a research and development program with an annual budget of 25 million DKK. The main objective of this programme is energy efficiency in sectors such as industrial, commercial, and residential [62].

District heating is Denmark's largest source of domestic heating, of which CHP plants generate about two-thirds; however, this share has fallen due to low energy prices which make cogeneration less profitable than the sole generation of heat. Until 2018, CHP was incentivized through the "basic amount" subsidy, which guaranteed a minimum price for the sale of electricity. In recent years, the Danish government has taken action to incentivize the diffusion of heat pumps. For instance, DKK 26.7 million was allocated to investments in 10 heat pump projects in 2015 [63] and another DKK 53 million was awarded in 2017–2018 [64].

3.6. The Netherlands

The Authority for Consumers and Markets (ACM) adopts a revenue cap for TSOs and a price cap for DSOs, with a regulatory period that lasts 5 years. A Totex approach is used, and efficiency and quality incentives are included. Typically, the cost of investments is at first incurred by the operator, who can include it to the RAB only after an ex-post assessment by the regulator where its need and efficient execution is assessed. Only a few large investments are approved ex-ante, thus ensuring less risk for operators as their costs are considered when fixing the price. The pricing mechanism imposed by the ACM on network operators offers strong incentives to reduce costs and to increase efficiency, due to the ex-post inclusion of the expenses incurred for investments and, at the same time, provides a low remuneration of the latter. Due to the regulatory method, the risk that operators have to bear is quite high, which leads to a low level of incentive for further investments compared to other European nations.

All decisions relating to RD&D's energy policies are the responsibility of the Ministry of Economic Affairs. Together with other institutions, the Ministry is responsible for guiding the choice of the necessary projects and the implementation of funding programs, such as the Top Sector program. This energy programme also focuses on ESI, which is considered a key issue by the Dutch Government in achieving a flexible energy system based mostly on RES. Table 6 presents an overview of the major recent network innovation projects in the Netherlands.

Table 6. Overview of network innovation projects in the Netherlands.

Project Category	Project	Incentive Mechanism	Source of Funding	Total Budget	Main Stakeholders
Power to gas or hydrogen	HEAVENN	Grants	EU, national and private funds.	€90 million	TSO and DSO
	Investment Agenda Hydrogen Northern Netherlands [1]	Subsidy to hydrogen production	Public and private funds.	€2.8 billion	TSO and DSO
Energy systems integration	Integrated Energy System Analysis	Grants	National funds	€ 1.8 million	TSO and DSO
	Top Sector projects	Grants	Top Sector programme	€ 2.8 million	TSO and DSO

Source: Elaboration on data available from Appendix B. [1.] This project has been only announced.

In total, the Netherlands has invested approximately €1.8 billion over the years in RD&D projects [65]. The Dutch priorities were mostly renewable resource projects, which received 44% of the total funds, and in second place those related to energy savings, with a share of 32%. A minority share was attributed to energy storage and hydrogen projects, which together contributed only 8% to the total.

4. Discussion

What emerges from looking at investment levels throughout the six countries is how little ESI investments amount to. The number of ESI projects across the six countries is a handful. In the UK, we identified only one ESI project financed through NIC/NIA; in Denmark, national funding programs financed only a few small integration projects. Most countries do not have any. The picture changes only slightly if we look at ESI-enabling technologies, with some level of investment in SG throughout the six countries but with low investments in storage and conversion systems. Different countries focus on different technologies, such as CHP in Germany and Denmark or P2G and hydrogen in the Netherlands. We attribute the lack of investments in integration projects to economic and policy barriers [13]. Among them, limited coordination between network operators, limited access to data by network users, lack of incentive regulation mechanisms which specifically target ESI related outputs, and lack of flexible approaches concerning the ownership and operation rights of innovative technologies such as storage and conversion systems. What kind of policy solutions are needed to overcome these barriers is a matter of further research.

The analysis shows a large difference among regulators in the approaches taken to support innovation. While in the UK, France, and Italy the regulatory frameworks are designed to provide financial incentives for investments in innovation, such support is provided through European and (mostly) national funds in the remaining countries. Apparently, those countries that adopt a government-driven approach show higher levels of investment and a greater number of integration projects. However, the differences within groups are larger than that between groups, making it hard to draw any robust conclusion. The two approaches have different ways to finance investments, with funds coming from network charges in the regulation-driven approach and from general taxation in the government-driven. This means that, although direct financing may lead to higher investments, it can also hide the real cost of innovation in the energy sector and could provide utilities with less incentive to consider innovation as business-as-usual, as these funds come from outside of their revenue allowances.

We note a marked difference in how sophisticated the incentives are among countries that adopt a regulation-driven approach. Both France and Italy only use input-based methods by raising the revenue cap or the WACC. The UK, on the other hand, adopts a variety of output-based and input-based mechanisms, and it takes a holistic approach to innovation in the energy sector. Nevertheless, the results in terms of investments in ESI are underwhelming in all three cases. This analysis looked only at ESI or ESI-enabling projects, that is, projects either on the integration of energy networks or on storage systems, conversion technologies, and SG. The conclusions we can draw are therefore limited to the effectiveness of these different schemes in incentivizing investment in integration, and not in innovation in general.

Our approach presents a series of limitations. The analysis gives a snapshot of the regulatory framework and of investment in ESI in each country. This provides preliminary information on the effectiveness of adopted policies on ESI investments, which can offer some useful guidance to assess whether further action is needed to incentivize its diffusion. However, the novelty of ESI and of some of the analyzed policies do not provide us with enough data to perform a quantitative analysis of the impact of the regulatory frameworks. In 5–10 years, further research could quantify the impact in terms of investments generated and the results of innovation. A further limitation is given by the difficulty of gathering data. Although, to the best of our knowledge, we included every integration project in our analysis, some may have escaped our scrutiny.

5. Conclusions

The European Union is moving towards a zero-emission economy, requiring member states to emphasize decarbonization and electrification policies. Achieving this plan requires extensive adoption of RES and DG, and an integrated energy system can provide an efficient solution while offsetting network flexibility and security problems caused by these technologies.

In this work, we systematically analyzed the regulatory frameworks and support schemes to innovation in six EU countries. We reported on investments in ESI and ESI-enabling projects in each country, categorizing them by technology domain and providing information on budgets, incentive mechanism, and source of funding. This analysis links the level of investment to policies adopted in each state. We find that investments in integration are very low in all countries, both for ESI-enabling technologies and for ESI projects. We derive that there is a need for stronger policy intervention to foster the integration of the energy systems. Further research is needed to establish what kind of policy solutions are required.

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Abbreviations

ACM	Authority for Consumers and Markets
ARERA	Autorità di Regolazione per Energia Reti e Ambiente
CHP	Combined Heat and Power
CRE	Commission de Régulation de l'Énergie
DERA	Danish Energy Regulatory Authority
DG	Distributed Generation
DH	District Heating
DKK	Danish Krone
DR	Demand Response
DSO	Distribution System Operator
DUR	Danish Utility Authority
EB	Electric Battery
EDUP	Energy Technology Development and Demonstration Program
ENTSO-E	European Network of Transmission System Operators for Electricity
ENTSOG	European Network of Transmission System Operators for Gas
ESI	Energy Systems Integration
EU	European Union
ICT	Information and Communications Technology
IRM	Innovation Roll-out Mechanism
NIA	Network Innovation Allowance
NIC	Network Innovation Competition
P2G	Power To Gas
PV	Photovoltaics
R&D	Research And Development
RAB	Regulatory Asset Base
RD&D	Research, Development and Demonstration
RES	Renewable Energy Sources
RIIO	Revenue equals Incentives plus Innovation plus Outputs
SG	Smart Grids
TSO	Transmission System Operator
UK	United Kingdom
WACC	Weighted Average Cost of Capital

Appendix A

In this Appendix, we describe some ESI projects that are being run in the six countries. The projects listed here serve as an example of the integration projects that were considered in the overview of Section 3. These projects are mainly located in those European States which allocate a wider range of public funds to develop innovative energy solutions such as Germany, Denmark, and the Netherlands.

Flexible Residential Energy Efficiency Demand Optimization and Management (FREEDOM) (the UK). FREEDOM is a £5.2 million development and demonstration project, started by the DSO *SP Distribution* in October 2016 and that lasted until January 2019. The project investment was financed under NIA with £4.5 million. The objective of the project was to convert households' home electric heating into a hybrid heating system that combines domestic gas boiler and air-sourced heat pump heating.

WindNODE (Germany). WindNODE is a project—financed under the SINTEG funding programme—which runs from 2016 to 2020 and has a budget of €66 million, €37 million of which granted by the Ministry for Economic Affairs and Energy (BMWi). *"The 'WindNODE' showcase unites five states in the north-east of Germany and Berlin. The goal is to efficiently integrate renewable energy into an energy system that works irrespective of the energy source and combines the electricity, heat and mobility sector. The 'WindNODE' project provides an ICT platform that connects generators and users of electricity, grids and markets and coordinates flexibility options (e.g., movable industrial loads, power-to-heat and cooling systems,* *electric mobility)"* [49]. As part of the project, WindNODE also intends to enhance grid flexibility by testing the integration of DH and the electricity network. It will be tested whether and to what extent a 120 MW power-to-heat plant can supply up to 30,000 households in winter and up to 300,000 in summer with the electricity surpluses generated by wind and PV in the surrounding area. The aim is to evaluate the coordinated management of bottlenecks within the new integrated network over the long-term, under the limitations posed by both the DH system and the electricity network.

Integrated Energy System Analysis (IESA) (the Netherlands). IESA is a project monitored by the New Energy Coalition (NEC) and conducted by the University of Groningen, The Netherlands Organization for Applied Scientific Research, Gasunie, and other partners of NEC. It runs for a period of 4 years, from 2018 to 2022, and it aims to provide an in-depth analysis of the linkages and the interaction between the energy sectors. This will help to understand the suitable models for the future integrated energy system. The total project costs will be €1.83 million, 73% of which is provided by national funding.

Smart Integrated Decentralized Energy Systems (SIDE) (the Netherlands). SIDE is a study commissioned by the Dutch Ministry of Economic Affairs and the Netherlands Enterprise Agency. The objective is to monitor four microgrid projects to evaluate all the societal and economic aspects. A SIDE network is composed of a set of integrated components (like solar panels, heat pumps, an electric vehicle, and a local management system), which allow local communities to self-manage supply and demand. In the study, the author analyzed the potential impact of diverse technologies on the four base cases, utilizing both real data and design criteria to create nine different scenarios. The examined scenarios describe a favorable situation for the SIDE approach, with the emergence of several best practices for the future. The author of the study found out that the SIDE model is cheaper in the long run compared to the conventional energy system. According to projections, a SIDE system has a payback time equal to 8.5 years compared to the 11.6 years of a traditional gas-based system. The implementation of SIDE systems among Dutch cities could significantly help the Netherlands in the achievement of a sustainable energy system. The SIDE study received approximately €46,000 through state subsidies.

Sustainable Energy Market Integration (SEMI) (Denmark). SEMI active for the period 2017/2020, will focus on the energy system integration from a market perspective. The main deliverables will be the Danish energy market models of the future. They investigate the potential synergies between energy sectors and the possible business models, which allow having optimal investments to reach the most coordinated energy system integration. The allocated budget is 7.74 million DKK, with a funding rate equal to 82%.

Enhancing wind Power Integration through optimal use of cross-sectoral flexibility in an integrated Multi-Energy System (EPIMES) (Denmark). EPIMES was launched in 2016, and it will end in 2019. EPIMES is an international project that has been carried out thanks to a partnership between Danish and Chinese institutions. The primary purpose of the project is to address the challenges related to wind integration on the power system. In particular, the research groups will utilize a multi-disciplinary approach to provide an optimal solution. They want to focus on the potential of cross-sectoral flexibility in a mixed electricity–heat–gas system from an integrated energy system perspective. The project is organized in different phases with specific targets. The ultimate step will be the test of selected solutions of cross-sectoral flexibility both in Denmark and China. The total budget allocated for the project is 7 million DKK, financing at 90% by national funding programs (Innovation Fund).

Smart citizen-centered local electricity to heat systems (SMARTCE2H) (Denmark). SMARTCE2H started in 2019, and it will end by 2021. The main purpose of the project is to demonstrate the technical and economic value of the installation of smart heat pumps in residential communities and in the DH network. This will be verified through test and demonstration activities on integrating electricity and heat system in Skive Municipality. Among the project's activities, there will also be a complete analysis to assess how regional grids can be optimized to form a local integrated community energy system.

The whole budget is 7.66 million DKK, 66% of which is allocated by a national funding program (i.e., the EUDP).

Hybrid Energy Networks. Denmark participates in the Hybrid Energy Networks, an international project that wants to assess the role of district heating and cooling in an integrated energy system context. The project will run for the period 2019/2022, and it will focus on determining the role of the district heating and cooling system in the implementation of hybrid energy networks. The project budget is 3.59 million DKK, 66% of which is provided by national funding (i.e., the EUDP).

Appendix B

Table A1. List of projects and sources.

Project Name	Source	Country
EnergyLab Nordhavn	http://www.energylabnordhavn.com	Denmark
Ecogrid 2.0	http://www.ecogrid.dk	Denmark
CITIES	https://smart-cities-centre.org	Denmark
FED	https://www.energiforskning.dk/da/project/flexible-energy-denmark-fed	Denmark
CORE	https://coreproject-dk.com	Denmark
BioCat	http://biocat-project.com	Denmark
Biocat Roslev	https://energiforskning.dk/en/node/9326	Denmark
P2G-Biocat 3	http://biocat-project.com	Denmark
EP2Gas	https://energiforskning.dk/en/projects/detail?program=All&teknologi=68&field_bevillingsaar_value=&start=&slut=&field_status_value=All&keyword=&page=37&lokalitet=All	Denmark
HyBalance	http://hybalance.eu	Denmark
SEMI	https://vbn.aau.dk/en/projects/semi-sustainable-energy-market-integration	Denmark
SMARTCE2H	https://energiforskning.dk/en/projects?program=All&teknologi=68&lokalitet=All&start=&slut=&field_status_value=All&keyword=	Denmark
Hybrid Energy Networks	https://vbn.aau.dk/en/projects/deltagelse-i-iea-dhc-annex-ts3-hybridenerginet-fjernvarme-og-fjer	Denmark
EPIMES	https://energiforskning.dk/en/node/8790	Denmark
Greater Copenhagen DH system	https://www.dti.dk/projects/project-experimental-development-of-electric-heat-pumps-in-the-greater-copenhagen-dh-system-phase-2/37419	Denmark
FLEX-TES	https://energiforskning.dk/en/projects/detail?lang=en&page=68	Denmark
LHCPB	https://vbn.aau.dk/en/projects/local-heating-concepts-for-power-balancing	Denmark
HEAT 4.0	https://www.energiforskning.dk/da/project/heat-40-digitally-supported-smart-district-heating	Denmark
Top Sector projects	https://www.topsectorenergie.nl/en	Denmark
SMILE	https://smile-smartgrids.fr/	France
FlexGrid	http://www.flexgrid.fr/	France
SG pilot projects	http://www.smartgrids-cre.fr/	France
11 pilots in isolated networks	Délibération de la Commission de régulation de l'énergie du 4 octobre 2018 portant décision sur la compensation des projets de stockage centralisé dans les zones non interconnectées dans le cadre du guichet d'octobre 2017.	France

Table A1. *Cont.*

Project Name	Source	Country
RINGO	Délibération de la Commission de Régulation de l'Energie du 7 décembre 2017 portant approbation du programme d'investissements de RTE pour 2018.	France
Jupiter 1000	https://www.jupiter1000.eu/	France
SINTEG	https://www.bmwi.de/	Germany
Energy Storage Funding Initiative—R&D and demonstration of storage technologies	https://www.bmwi.de/; https://forschung-energiespeicher.info/	Germany
KfW Banks—loans for EBs	https://www.bmwi.de/	Germany
CHP Act	Gesetz für die Erhaltung, die Modernisierung und den Ausbau der Kraft-Wärme-Kopplung. Kraft-Wärme-Kopplungsgesetz vom 21. Dezember 2015 (BGBl. I S. 2498), das zuletzt durch Artikel 2 des Gesetzes vom 17. Dezember 2018 (BGBl. I S. 2549) geändert worden ist.	Germany
WindNODE	https://www.sinteg.de/; https://www.windnode.de/	Germany
SG pilot projects	https://www.arera.it/	Italy
e-Distribuzione—SG projects	https://www.e-distribuzione.it/; http://www.ponic.gov.it/	Italy
e-Distribuzion—Open Meter project	Deliberazione 6 aprile 2017 - 222/2017/R/EEL - Sistemi di smart metering di seconda generazione (2G): decisione sul piano di messa in servizio e sulla richiesta di ammissione al riconoscimento degli investimenti in regime specifico di e-distribuzione S.p.a.	Italy
Terna S.p.A.—Project Lab and Large Scale Energy Storage pilot projects	http://www.terna.it/	Italy
HEAVENN	https://newenergycoalition.org/en/hydrogen-valley/	Netherlands
Investment agenda hydrogen Northern Netherlands	https://www.snn.nl/sites/default/files/2019-07/Investment%20Agenda%20Hydrogen%20Northern%20Netherlands%20-%20April%202019%20%285%29.pdf	Netherlands
Integrated Energy System Analysis	https://newenergycoalition.org/custom/uploads/2019/09/Project-Integrated-Energy-Systems-Analysis.pdf	Netherlands
Top Sector projects	https://www.topsectorenergie.nl/en	Netherlands
SIDE	https://www.metabolic.nl/projects/side-systems/	Netherlands
NIC and NIA projects	http://www.smarternetworks.org/	UK
FREEDOM	http://www.smarternetworks.org/	UK

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