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Market and regulatory factors influencing smart-grid investment in Europe: Evidence from pilot projects and implications for reform

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ABSTRACT

Electricity distribution system operators (DSOs) are expected to invest heavily in system innovation in the form of smart grids (SG) in order to help achieve energy policy goals. In this context, regulatory reforms to spur DSOs investments are considered a policy priority. Based on a review of the European regulatory status and using a dataset of 459 innovative SG projects, this study focuses on market and regulatory factors and performs a series of statistical tests to investigate how the different factor levels affecting SG investments in Europe. The results show that (1) lower market concentration in the electricity distribution sector (2) the use of incentive-based regulatory schemes; and (3) the adoption of innovation-stimulus mechanisms are key enablers of SG investments.

1. Introduction

Today's electric power industry faces challenges as large as any in its history in the form of climate change and the depletion of energy sources. In response, the European Union (EU) has established three key energy policy objectives related to the competitiveness, sustainability, and security of supply, which are underpinned by long-term energy targets. These targets include an increase of energy efficiency by at least 27% compared with the business-as-usual scenario, an increase of renewable energy supply by at least 27% of total demand, and a reduction in greenhouse gas emissions of 40% compared to 1990 levels.

The ambitious energy targets trigger new investment needs and call for new ways to plan, construct, and operate network infrastructures. Europe's electricity networks that have served well the needs of consumers for many decades will need to be expanded, upgraded, and modernized. At the transmission level, the expected increase in the penetration of variable renewable energy sources (RES) creates substantial needs for new cross-border transmission capacities (European Commission (EC), 2010; ENTSO-E, 2014; EC JRC, 2015). At the distribution level, several new challenges such as the rapid integration of distributed energy resources (DER) and the growing electrification of mobility will need to be met by a more intelligent and communicative electricity network, the so-called smart grid (SG).

Smart grids (SG) requires a fundamental transformation of the electricity industry's operating model in order to enable a more efficient allocation of energy resources (to meet energy demand) while ensuring the active participation of consumers (and "prosumers") in energy markets. However, such a transition away from the current centralised, top-down model will require considerable

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investment. Indeed, the International Energy Agency (IEA) is expecting electricity network investments in the range of €600 billion for Europe between 2014 and 2035 (IEA, 2014). The bulk of the forecast investment (≈ 80%) will be allocated to the development of the distribution network. Europe's industry association for electricity estimates a similar scale of investment over a shorter time period, forecasting a requirement of €600 billion by 2020, two thirds of which will be for distribution grids (Eurelectric, 2013). The magnitude of the expected investments arguably highlights the prominent position of smarter electricity grids on the current energy policy agenda.

SG investments are associated with the replacement or upgrading of physical infrastructure (e.g. new sensors, controllers), the integration of ICT infrastructure (e.g. software technologies, communication protocols) in the distribution system, and the implementation of innovative projects (Fox-Penner, 2010; Marques et al., 2014). The innovation path can be pursued through pilot[1] projects that advance our knowledge of the real-time operation of the grid. SG pilot projects may require significant upfront costs but have the potential to deliver important benefits for the project partners. Pilot initiatives can be beneficial in many ways; allowing the evaluation of innovative technologies in a real environment (e.g., viability and interoperability) and potential behaviour patterns of consumers as well as the broad range of diverse energy players' interactions. Over the last decade, 459 European SG pilot projects have been implemented, representing an investment of €3.15 billion (EC JRC, 2014), with the investment effort expected to intensify over the coming years.

European distribution system operators (DSOs) will have an important role to play, as they are the ones expected to carry the main investment burden. Since DSOs are regulated entities that have to cover their costs through regulated revenues only (Eurelectric, 2014), the unenviable job of balancing the expected benefits from SG investments with their capital costs will fall to national regulators (Fox-Penner, 2010). In this respect, regulation can have an important role in setting up a framework that fosters investment in SG development (Marques et al., 2014).

While in the last two decades the current regulatory frameworks for DSOs have largely focused on input-oriented goals, i.e. spurring productive efficiency, in recent years many regulators (such as Ofgem in UK; see Ofgem, 2010) are modifying their regulatory interventions to become more innovation-friendly, and to ensure that new forms of investment are reflected in regulated tariffs (CEDEC, 2014). In a recently published survey, DSO directors claimed that despite the recognised political will for fostering SG solutions, most regulatory authorities treat R&D and demonstration projects as any other cost without providing adequate incentives (Eurelectric, 2014). An effective and successful regulatory scheme should strike a balance among the goals of consumer affordability, investment incentives, the quality of supply, and the economic viability of the DSO.

This paper intends to explore the effect of specific market and regulation factors[2] on the level of investments in SG pilot[3] projects in Europe using an original dataset of 459 SG projects in 30 European countries in the period 2002–2014. Among the variety of market and regulatory factors, the study is particularly concerned with the following:

i. Distribution-sector concentration: reflects the level of market concentration in the electric power distribution sector;
ii. Regulatory-mechanisms: reflects the capacity of the regulatory scheme to provide incentives to DSOs for increasing cost efficiency or productivity;
iii. Innovation-stimulus mechanisms: refers to the mechanisms designed by regulatory authorities to stimulate the implementation of pilot projects.

For each of them, this study focuses on how the factor levels[4] might affect investments in SG pilot projects in Europe. In this context, the study provides insights on potential regulatory reforms toward an updated and innovation-friendly framework that will incentivize SG investments by DSO.

The paper is structured as follows. Section 2 provides a detailed description of the data-collection process. Section 3 presents the regulatory factors that will be used for subsequent analysis. Section 4 presents the steps of the analysis and discusses the results. Section 5 sets out the conclusions, discusses the limitations of the analysis, and proposes future work.

2. Data

2.1. Data sources

The study is based on two comprehensive sets of data: a database with 459 SG pilot projects that were started in between 2002 and 2014 and a compiled list of the key features (factors) associated with the regulation of electricity distribution networks. Both datasets concern the European territory and in particular 30 European countries: the 28 European Union member states (EU-28), Switzerland, and Norway.

The SG pilot projects database is the product of data collection efforts made by the European Commission's Joint Research Centre (JRC), which conducted a related survey annually from 2011 to 2014. The use of JRC's database assures the neutrality and reliability of the data. Additionally the data should be considered homogeneous in the sense that all the projects included satisfy certain criteria: that is, all of the projects are being implemented in Europe, are at the R&D or demonstration stage of development (pilots), and concern new technologies[5] and ICT capabilities aiming to make the grid smarter. Since there is no globally agreed upon definition of a smart grid (Clastres, 2011), the study follows the EC JRC (2012) approach[6] for compiling the SG project database.

For the mapping of regulatory factors concerning DSOs in Europe, we gathered information from a broad range of sources, including institutional and consulting reports as well as academic research. Initially, we sourced data from two Eurelectric reports (Eurelectric, 2014, 2013) as well as from a consulting company (Ernst and Young , 2013). All the collected data were cross-referenced by analysing the annual reports of European national energy regulators (NERs) as well as recently published papers (e.g. Cambini and Rondi, 2010). Where discrepancies were found, we relied on the data derived from the NERs' reports as our primary source.

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[1] We distinguish between deployment and pilot projects. Deployment projects are large scale commercial projects, while pilot projects are R&D or demonstration projects targeting on innovation.

[2] A "factor" is a vector whose elements can take on one of a specific set of values.

[3] For the sake of simplicity, we will use the term SG investments referring to this part of investments that concerns innovative projects.

[4] The set of values that the elements of a factor can take are called levels (factor levels).

[5] With respect to SG technologies, the database does not include projects concerning smart meter installations. Smart meter is considered a mature technology in deployment phase and many European countries (e.g. Italy, Sweden) have already completed roll-out programs.

[6] Smart Grids is an upgraded electricity network enabling two-way information and power exchange between suppliers and consumers, thanks to the pervasive incorporation of intelligent communication monitoring and management systems.

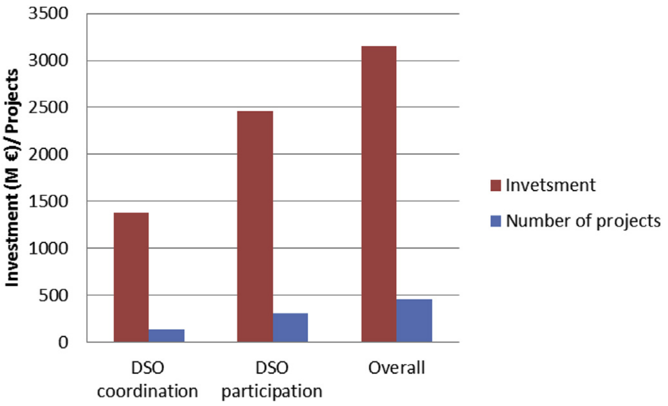

Fig. 1. Overall investments, DSO led investments and DSO participation investments in terms of project number and investment.

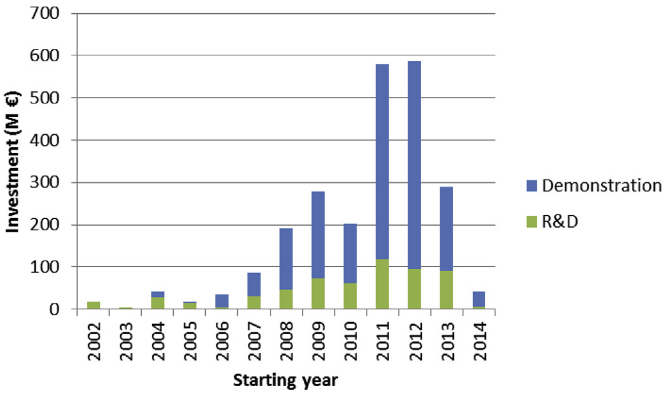

Fig. 2. The distribution of SG investments by starting year of the project, for the projects where at least one DSO participates in.

2.2. *DSO involvement in SG pilot investments*

The set-up of the smart electricity system is expected to yield benefits all along the value chain of electricity sector, from generation to consumption; however, the bulk of investment will be required at the distribution level. Undoubtedly, DSOs will bear the lion's share of the initial investments necessary for commercial solutions (Eurelectric, 2011). Yet, the pace of DSOs' investments in SG technologies may be affected by traditional regulatory schemes that, though providing adequate incentives for enhancing productive efficiency, may lead to sub-optimal incentives associated with, for example, low regulated rates of return and no premium for demand uncertainty.

Despite the purported ineffectiveness of regulatory schemes to incentivize SG investments, the data seem to confirm the leading role of DSOs in promoting SG development in Europe. DSOs/utilities[7] are best represented in the majority of SG pilot projects in Europe and are at the forefront in terms of investment (EC JRC, 2014). Out of the total number of 459 projects, DSOs are involved in the 66% of them. In many of these cases (30%), DSOs have the prominent role of coordinator (lead organization). In terms of budgets, DSOs participate in 78% (€2.46 billion) of the total investments while they lead 44% (€1.37 billion) of the total investment efforts as shown in Fig.1.

Fig. 2 shows the investments in R&D and demonstration projects by starting year when at least one of the project partners is a DSO. DSOs are involved in projects with an average budget of €8.6 million. The data show a sufficient level of maturity of SG technologies since the investments in demonstration projects outnumber the ones in R&D. Around 76% of the analysed investments are classified as demonstration projects, whereas the remainder are R&D projects.

SG projects in Europe have experienced significant growth over the last decade (2004–2014). Especially between 2008 and 2014, the number of SG projects increased rapidly with more than 98% of the collected projects having started during this period of time. More precisely, the development of the field can be split into two phases: a first phase (between 2002 and 2007), with a relatively low average annual budget of €33 million and a second phase (between 2008 and 2014), with an average annual budget equal to €350 million. This sharp increase in the level of investment may be due to several factors. Technological maturity or newly introduced policies may partially explain the investment discrepancy between the two identified phases. Ginsberg et al. (2010) argue that the stimulus packages launched by governments after the financial crisis in 2008 may have significantly affected investment decisions. At the European level, SG initiatives have received wide support through different channels of funding over the last years, including the 7th Framework program, the recovery fund, and the infrastructure package (EC JRC, 2013; 2014). National funding is also increasingly supporting SG investments in several European countries (see e.g. EC JRC, 2014). These various funding initiatives are targeting pilot projects across different countries and technological applications.

2.2.1. *Handling and normalization of SG investment data*

The data confirm the high participation of DSOs in SG projects as well as their leading role in many of them (Fig. 1). For the purpose of our analysis, the investment data were refined by excluding the projects where DSOs do not participate. The deployment of a SG imposes a change in the electrical architecture and design of the distribution networks which are operated by the DSOs. Since regulation directly affects DSO budgets and in turn their ability to raise capital for the implementation of innovative SG projects, we examine the correlation between the DSOs' SG investments and the regulatory factors, restricting our analysis to DSO-participation projects. Thus, 150 projects, accounting for an overall investment of around €0.7 billion were excluded. Additionally, 24 projects with insufficient budget information were not taken into consideration. After refining the data, we allocated the projects' budgets across the different countries. When a project had several implementation sites with participants coming from different European countries, the budget was allocated evenly (without weighting) among them.

As outlined above, SG investments span a period of thirteen years (2002–2014). This study uses only the data from a six-year observation period, from 2008 till 2013. First, as shown in Fig. 2, the level of investments in between 2002 and 2007 was particularly low, probably due to the uncertainty related to the returns on such capital expenditures. Second, the investment data for the period 2002–2007 are considered somewhat unreliability and there is a high probability that some investments were not listed prior to the data collection efforts started in 2010 (for the release of the first EC JRC inventory). Finally, for the period 2002–2007, data for the regulatory mechanisms to support SG are not available in the corresponding literature. With respect to the factor

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[7] With the term “utility” we refer to these integrated energy companies whose core business activities combine electricity distribution with supply (retail) and/or more rarely with small-scale generation. These utilities may be exempted from the EU unbundling requirement as they serve less than 100.000 customers. This is typically the case of utilities in Austria, Germany and Nordic countries. For the sake of simplicity, we henceforth use only the term DSO to describe both energy distribution firms and integrated, unbundled utilities.

Table 1
The normalized SG investments and the three analysed regulatory factors for 30 European countries (EU-28, Norway and Switzerland).

Country	Country code	Investment (€/M€ of GDP)	Investments (€/capita)	Distribution-sector concentration	Regulatory-mechanisms	Innovation-stimulus mechanisms
Austria	AT	193.80	7.03	Low	Incentive	Adj. Rev.
Belgium	BE	228.46	7.77	Low	Cost	None
Bulgaria	BG	56.77	0.30	Medium	Incentive	None
Switzerland	CH	26.19	1.53	Low	Cost	None
Cyprus	CY	55.49	1.27	High	Cost	None
Czech Republic	CZ	219.48	3.31	Medium	Hybrid	None
Germany	DE	109.19	3.54	Low	Incentive	None
Denmark	DK	566.12	24.89	Low	Hybrid	Adj. Rev.
Estonia	EE	64.73	0.80	Medium	Hybrid	None
Greece	EL	76.20	1.49	High	Cost	None
Spain	ES	174.56	4.06	Medium	Hybrid	None
Finland	FI	243.26	8.77	Low	Hybrid	Adj. Rev.
France	FR	191.15	6.18	Medium	Incentive	None
Croatia	HR	42.64	0.45	High	Cost	None
Hungary	HU	82.83	0.83	Medium	Incentive	None
Ireland	IE	88.99	3.35	High	Incentive	Adj. Rev.
Italy	IT	136.73	3.72	Medium	Hybrid	Extra WACC
Lithuania	LT	84.32	0.85	High	Incentive	None
Luxembourg	LU	68.33	5.47	Medium	Incentive	None
Latvia	LV	26.77	0.27	Medium	Hybrid	None
Malta	MT	42.80	0.70	High	Cost	None
Netherlands	NL	155.37	5.93	Medium	Incentive	None
Norway	NO	47.08	3.27	Low	Incentive	None
Poland	PL	19.21	0.18	Medium	Hybrid	None
Portugal	PT	306.46	5.11	Medium	Hybrid	Extra WACC
Romania	RO	27.55	0.18	Medium	Incentive	None
Sweden	SE	234.89	9.59	Low	Incentive	None
Slovenia	SI	337.71	6.05	High	Incentive	Adj. Rev.
Slovakia	SK	68.75	0.88	Medium	Incentive	None
United Kingdom	UK	203.18	6.10	Medium	Incentive	Adj. Rev.

Note: The abbreviation “Adj. Rev.” stands for the term “Adjustment of Revenues”.

“innovation-stimulus mechanisms”, most of the NERs introduced this type of incentives after 2008.[8] In the light of these issues, the study relies on a six-year observation period, from 2008 till 2013.

As shown in Table 1, the SG investments are not uniformly distributed across Europe and the great majority of the spending is in central European countries. Disparities in the distribution of SG investment may be explained by the socioeconomic inequalities among countries (e.g. gross domestic product (GDP), population) or even by inequalities in electricity consumption patterns. In particular, socioeconomic factors can considerably affect the level of SG investments, undermining the comparability of data in a notionally common scale. To overcome this problem, country investment data were normalized by dividing by the respective GDP and population data. Both the GDP and the population data were obtained by the Eurostat's website (Eurostat, 2015). For each individual country, the two normalisers were calculated as an average of six years values for the period 2008–2013.[9] Following the normalization process the data were converted into ratios; Euro of SG investment per million Euros of GDP (€/M € of GDP) for the GDP normaliser and Euro of SG investment per capita (€/capita) for the population normaliser. For more details about the values prior to and after normalization, see the table of Appendix I.

3. DSO market conditions and regulatory schemes

This section discusses the grouping of 30 European countries with respect to the three different regulatory characteristics introduced above: distribution-sector concentration, regulatory-mechanisms, and innovation-stimulus mechanisms.

3.1. Distribution-sector concentration

Electricity DSOs manage the power distribution system consisting of cables that deliver electric power from the transmission level to the end users. Generally, DSOs operate in a specific area of a country where they act as the monopolistic network operator. However, over a country many DSOs may operate and some potential degree of competition among them may emerge as long as the regulators adopt comparative benchmarking to assess their performance. Focussing on the level of distribution-sector market concentration is therefore an interesting feature because it provides suggestions on the potential role of scale or scope economies in spurring SG investments. Moreover, the criterion of “distribution-sector market concentration” is an important structural factor that might indirectly be affected also by regulatory decisions[10]. We consider the following question: “What is the number of distribution systems or DSOs and their respective shares of the overall

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[8] The British energy regulator (OFGEM) and the Danish Energy Regulatory Authority (DERA) were the only ones, among the European NERs, who introduced such type of innovation incentives before 2008. OFGEM initiated an innovation incentives in 2004 and DERA in 2008.

[9] The average method was used for achieving more accurate results while the observation period corresponds with the selected SG investments' period.

[10] NERs cannot intervene in the unbundling processes of utilities neither to inhibit DSOs from adopting corporate solutions, such as mergers and split-ups. However, with respect to the unbundling requirement of the Third Energy Package (Directive, 2009/72/EC), European energy regulators are responsible for the monitoring of the requirement across the board, in order to assess how the rules function in practice (CEER, 2013). With respect to mergers and split-ups, most of the European NERs have adopted specific “mergers and acquisitions” policies, dealing with the regulatory issues raised by mergers or comparable transactions in the electricity distribution sectors. For instance, a relevant policy was published by OFGEM in 2002. Usually NERs provide advice to the national merger authorities on the impact of mergers in the electricity sector but they do not have formal merger control powers.

capacity in the distribution sector of the electricity markets?" To define the precise criteria for categorization, this study adopts the approach followed by Eurelectric (2013), which is predominantly based on a three-firm concentration ratio (CR_3), to measure the total market share of the three largest firms in the industry. European countries' markets can be assigned to three broad categories: a) high concentration, b) medium concentration, and c) low concentration (see Table 1).

Countries with one distribution system or DSO serving 99%–100% of the distributed power are assigned to the "high concentration" group. The group "medium concentration" includes the countries where one dominant DSO serves about 80% of distributed power market or the three largest DSOs serve more than 60% of the market (with several smaller DSOs serving the rest). A typical example of medium concentrated market is the Italian, where 140 DSOs operate the electricity distribution networks with one DSO covering 86% of the demand and 49 DSOs having less than one thousand customers (RSE, 2014). As "low concentration" national markets, are grouped the ones where the three largest DSOs deliver about 50% of the distributed power. For example, in Finland, Norway, and Sweden the three biggest companies have a market share of 41%, 33%, and 51% respectively (NordREG, 2011).

In the majority of European countries, the markets' concentration ratio is either medium or low. Indicatively, half of the national markets present in the analysis are categorized as "medium concentrated", while eight of them as "low concentrated". Only in a few countries (Greece, Slovenia, Ireland, Lithuania, Malta and Cyprus) do the markets reflect high concentration levels. In Malta and Cyprus, the DSOs also serve a small number of customers, typically less than one million.

Due to the transformations of the European electricity markets, the number of DSOs is continuously changing (Jenkins et al., 2000). Over the last years, the split-ups and mergers of DSOs is a common phenomenon in the European countries and two opposing trends can be observed. The cases of Denmark and Romania are of particular interest, since their distribution-sector concentration levels have gone up and down, respectively, the last few years. In Denmark, due to several mergers, the number of Danish electricity distribution companies has decreased from 107 in 2006 to 77 in 2011 (Schweinsberg et al., 2011) making the market more concentrated. The main goal of mergers is the achievement of efficiency improvements by network utilities (Lopes Ferreira et al., 2011). On the other hand, in 2001, the Romanian distribution monopoly (Electrica) was split up into eight geographically-based distributors with five of them becoming private corporations.

3.2. Regulatory-mechanisms

Different criteria can be used to group European countries according to regulatory models. Considering regulatory capacity to induce cost efficiency or productivity by providing relevant incentives to DSOs, this study identifies three broad categories of models: a) incentive-based models, b) cost-based models, and c) hybrid models.

3.2.1. Incentive-based models

A loose definition describes an incentive-based regulation scheme as any model where the regulator delegates certain pricing decisions to the firm and that the firm can reap profit increases from cost reduction (Vogelsang, 2002). Price-cap regulation has typically been regarded as the initial incentive-based regulation model, since it was introduced in the UK during the privatisation and liberalization era to motivate cost minimization by regulated utilities. Under the price-cap framework, a CPI-X mechanism is applied where revenue needs are adjusted by inflation minus an annual efficiency factor [X]. Other types of incentive-based regulatory models include revenue caps, revenue or profit sharing, performance measurement (yardstick) regulation, and menus[11] (Joskow, 2008). Usually, in countries where incentive-based regulatory schemes are applied, more than one type of model is used. For instance, the Austrian regulatory system is based on a combination of revenue caps and two separate benchmarking (yardstick) techniques (Frontier-Economics, 2012).

Today the majority of European countries use incentive-based regulatory schemes. Out of the 30 countries represented in our analysis, half of them use an incentive-based regulatory model. Norway, a country among the first (along with the UK) to implement market-oriented reforms in the electricity sector, switched from rate-of-return (RoR) to incentive-based regulation in 1997. Today, Norway is applying a form of quality-adjusted revenue-caps. In the Netherlands, incentive-based regulation has been applied since the first price control in 2001. By comparison, other countries (like Spain and Germany) have introduced reforms more recently. In Germany, BNetzA (the German NER) applied a cost-based regulation from 2001 to 2008, before switching to an incentive-based scheme in 2009 (Frontier-Economics, 2012). In 2008, Spain established a new regulatory framework for electricity DSOs based on revenue caps and a review period of four years (Schweinsberg et al., 2011).

3.2.2. Cost-based models

Along the spectrum of regulatory reforms, price-cap regulation is considered a high-powered incentive scheme, particularly when compared to cost-based (such as rate-of-return) regulation whereby prices are kept close to realized costs, thereby ensuring that the earnings are close to a target level. As pointed out in the economic literature, cost-based regulation determines an allowed rate of return on investment for the company, and every price review rates are adjusted so as to ensure the firm to earn the authorized return (Armstrong and Sappington, 2006). Cost-based regulation models may provide relatively weak incentives for cost efficiency, but many costs are not totally uncontrollable. In practice, countries adopting cost-based models usually apply a cap on operating expenditures (OPEX). For example, the regulatory model implemented in Greece includes an OPEX clearance term in the regulation formula triggered by a 3% difference between actual and budgeted OPEX (RAE, 2012). Similarly the cost-based regulatory schemes of Belgium, Switzerland, Cyprus, and Malta include analogous restrictions.

3.2.3. Hybrid models

In between the cost-based and incentive-based models are different combinations of the two types of regulation, or so-called hybrid models (Blank and Mayo, 2009). In practice, many hybrid models follow a cost-based approach for the treatment of capital expenses (CAPEX) and an incentive-based approach for the treatment of OPEX.

One often sited example is the Finish model where the regulatory authority, EMA, applies an ex-ante RoR regulation with incentives properties. A benchmarking analysis for determining the reasonable level of operating expenditures (the efficiency target) is combined with a general efficiency requirement (2.06%) targeted to the operational cost (Tahvanainen et al., 2012). More precisely, the general efficiency target of 2.06% applies to total expenditures (TOTEX), defined as the sum of OPEX and the estimated cost of

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[11] Menus or options allow the regulated utility a choice among different incentive regulation plans. This choice usually consists of combination between price caps and profit sharing (Vogelsang, 2002).

customer outages (Eurelectric, 2014).

Another example is the Italian regulatory model. AEEG, the Italian NER, has prompted DSOs and transmission system operators (TSOs) to trim down OPEX costs by a factor (X) year-on-year, while the invested capital is remunerated at a rate that is fixed for four-year periods (Cambini and Rondi, 2010; Crispim et al., 2014). Since 1999, Portugal has adopted price-cap regulation, applying efficiency measures on the total cost of the DSOs. In the allowed returns, CAPEX is fully considered and only the OPEX figure is affected by the efficiency measures (ERSE, 2011). In Denmark, DERA determines the maximum return on grid assets allowed for each individual DSO annually and incorporates that return on the existing revenue cap mechanism (CEER-DERA, 2014).

In Estonia, a combination of both RoR and incentive-based regulatory regimes is used (ERRA, 2009). In the case of operating and maintenance costs, the regulatory formula provides for a CPI-X allowance, with the X factor set at 1.5% (Moody's, 2013). New investments, as agreed at the regulatory reviews, are fully reflected in the company's regulatory asset base (Moody's, 2013).

3.3. *Innovation-stimulus mechanisms*

Over the last years, NERs have developed dedicated incentive-mechanisms in an effort to stimulate innovation within the distribution system. Often targeted at SG technologies or at commercial arrangements, these mechanisms are designed to support innovation initiatives that DSOs are unlikely to undertake in the absence of incentives.

With respect to the innovation incentives provided by NERs, the study identifies two broad categories of regulatory frameworks. The first category includes frameworks with particular incentive mechanisms for innovative initiatives and the second includes frameworks where innovation-related investments are treated like other costs. So far, within the first category, the two variants of incentive mechanisms that have been developed to support the pilot investments are: (1) the provision of higher rates of return (i.e., adding an extra or bonus component to the regulatory weighted average cost of capital or WACC), and (2) the adjustment of revenues (i.e., providing an extra allowance or specific rewards due to performance targets). However, as can be seen from Table 1, in most European countries R&D and demonstration expenses are treated like any other cost; i.e. there is no specific compensation for the risks involved in testing new technologies and processes (Eurelectric, 2014).

At the moment, two countries apply an extra WACC mechanism. In Portugal, the regulator allows the DSO a 1.5% premium return on “smart” investments if the project is expected to provide for an overall efficiency gain, with OPEX savings over time compensating for the initial additional CAPEX (Crispim et al., 2014). The premium of 1.5% was estimated in order to improve efficiency in the allocation of resources while avoiding distributional distortion (Marques et al., 2014). Similarly, in Italy, AEEG introduced a competition-based procedure providing specific incentives for innovative demonstration projects related to the active distribution network. To generate interest by DSOs, these pilot programs allowed for a 2% premium over the cost of capital for a limited time period of 12 years (Crispim et al., 2014).

On the other hand, in several countries, NERs adjust revenues by providing an extra allowance. Being among the first NERs that have introduced specialised incentive mechanisms, the Danish regulator applies a public service obligation-financed mechanism (ForskEL). The ForskEL mechanism is dedicated to support R&D and demonstration of environmental friendly technologies and provides annual funding of DKK 130 million (Energinet.dk, 2015).

Probably the most well-known example comes from the UK where, in December 2009, OFGEM announced a funding mechanism (Low Carbon Network Funds-LCNF) of £500 million over the period 2010 to 2015 to support competitive tenders for “large-scale trials of advanced technology including smart grids”, as part of DPCR5, and only applicable to electricity distribution companies (Crispim et al., 2014). In 2015, with the introduction of RIIO-ED1, the LCNF was replaced by a new funding scheme, called Network Innovation Competition (NIC). NIC intends to provide incentives to DSOs for the implementation of SG solutions.

In Ireland, in 2011, the Commission for Energy Regulation (CER) introduced an extra-allowance mechanism for incentivizing DSO to carry out research and development and sustainability activities. The total amount of the projected fund equals €18.2 million and will allow DSOs to explore technological advances in areas such as smart grids, generation integration, and adaptation of new network devices to support the integration of renewable generation into the network and improve the reliability of service (CER, 2010).

In Slovenia, the NER allows additional cost for SG projects (including pilots) to be included in allowed revenues in the 2012–2014 regulation period (Eurelectric, 2014). In particular, DSOs receive a one-time payment of 2% of the value of the realized SG investments (in addition to regular income from grid regulation), in the year in which the asset is put into service (Agencija za energijo, 2016; Eurelectric, 2014).

In Finland, DSOs can cover some of their investment costs through the innovation incentive system. As part of the innovation incentive system, the EMV can approve R&D related expenditures up to a maximum of 0.5% of a DSO's annual turnover (NordREG, 2011).

In Austria, the regulatory system provides incentives for cost reductions as companies must follow a regulatory efficient path (CEER, 2014). Additionally, E-Control (the Austrian NER) applies an incentive factor to stimulate investments in innovation. The investment factor constitutes a cost-based element in the incentive-based regulatory system (Frontier-Economics, 2012).

Both of these variations in innovation-stimulus mechanisms typically encompass a tendering procedure. As has already been discussed above, tendering is a common approach followed by NERs in the UK, Italy, and Denmark. Incentive-mechanisms provide tendering funds for which DSOs can compete with innovative investment models. The qualified tenders are allowed an increased remuneration for certain innovative investments compared to their conventional investment counterparts.

In Norway and France, the NERs have recently adopted incentive mechanisms for investments in innovation. Since 2013, the Norwegian NER has been providing extra income of up to 0.3% (book value * 1.01) on some innovative projects (Eurelectric, 2014). In France, a new instrument that includes a dedicated amount for R&D and pilots was issued at the end of 2013 (Eurelectric, 2014). If the DSO spends less than the projected allowance, the remaining amount is returned to the customers benefit, while if the company overspends is at its own risk. Due to the fact that these developments are quite recent, thus having minor effect on the investments for the observation period 2008–2013, the Norwegian and French regulatory frameworks were not considered as of providing specialized innovation incentives for the purpose of our analysis.

4. Analysis

For the three regulatory factors previously described, individual statistical hypothesis tests were carried out in order to discover the correlation between the dependent variable, namely the level of SG investments in the European countries, and each of the regulatory factors. The individual regulatory factors were used as categorical

Table 2

The descriptive statistics: mean, standard deviation, maximum/minimum values (Max/Min) for the country-groups for each regulatory factor considered in the analysis.

Descriptive statistics									
Factor	Groups	€/Capita				€/M€ of GDP			
		Mean ($\overline{X}$)	Standard deviation	Max/Min	n. obs.	Mean ($\overline{X}$)	Standard deviation	Max/Min	n. obs.
Distribution-sector concentration	High	2.02	2.0	6.0/0.45	7	103.9	104.7	337.7/19.2	7
	Medium	2.89	2.4	6.2/0.18	15	120.2	85.8	308.5/19.2	15
	Low	8.30	0.6	24.9/1.53	8	206.0	168.8	566.2/26.2	8
Regulatory-mechanisms	Incentive-based	3.97	2.9	9.6/0.18	15	129.8	86.5	337.7/27.5	15
	Hybrid	5.68	7.7	24.9/0.18	9	195.5	170.8	566.1/19.2	9
	Cost-based	2.20	2.7	7.8/0.45	6	78.6	75.0	227.9/26.2	6
Innovation-stimulus mechanisms	No Incentive	2.67	2.75	9.6/0.18	22	95.5	70.9	234.9/19.2	22
	Extra WACC/Adj. Rev.	8.13	6.99	24.9/3.35	8	259.6	148.7	566.1/87.8	8

Note: The abbreviation “n. obs.” stands for the term “number of observations”.

variables to form different groups of observations from the sample population. Then, differences in means among the groups were studied.

The analysis was performed according to three discrete steps. First, the observations (SG investments per country) were sorted into relevant groups for each regulatory factor. For each group and each factor respectively, basic descriptive statistics (means and standard deviations) were calculated to provide both quantitative and visual information. Second, the data were assessed in terms of satisfying certain assumptions and these results were used to formulate our hypotheses. Statistical testing requires the assessment of three basic assumptions about the statistical population: (1) the normality of the distributions, (2) the independence of the observations, and (3) the homogeneity of variances (homoscedasticity). In the third and final step, the statistical hypotheses were tested according to a selected level of significance.

4.1. *Descriptive statistics*

At its core, this study is concerned with three distinct yet alike sets of analyses, one for each regulatory factor discussed in Section 3. For each analysis, the individual thirty observations of the dependent variable (SG investments per country) are classified into different groups (levels). The observations were grouped into three groups for the factors “distribution-sector concentration” and “regulatory-mechanism” and in two groups for the factor “innovation-stimulus mechanisms”. For the factor “distribution-sector concentration” the formed groups contain 7, 15, and 8 observations while for the factor “regulatory-mechanism” the formed groups contain 6, 9, and 15 observations. For “innovation-stimulus mechanisms” the groups contain 8 and 22 observations. Table 2 summarizes the group-formation results along the basic descriptive statistics. In Section 4.3 we compare the values from the different groups. The analysis is further extended to our main variables of interest, i.e. investment per capita and investment per million euros of GDP.

4.2. *Statistical hypothesis tests' assumptions*

4.2.1. *The assumption of normality*

Assessing the assumption of normality is of paramount importance for deciding the use of a parametric or non-parametric statistical test. Parametric statistical analysis assumes a certain distribution of the data, namely the “normal” one, which in case of violation may lead to invalid and unreliable interpretation and inference (Razali and Wah, 2011). On the contrary, non-parametric statistics are distribution-free methods and therefore do not rely on the estimation of population parameters (StatSoft, 2015).

To check for the normality of the distribution, we used the Shapiro–Wilk test (S–W test) against the alternative of Kolmogorov-Smirnov test.[12] S–W test is considered the most powerful normality test available (Razali and Wah, 2011) as it detects small departures from normality. Being aware of the limited applicability of S–W test for small-size samples (low number of observations), the test was mainly applied to the samples with more than 8 observations. Appendix II provides the results obtained by the S–W test.

In the cases where S–W test failed to detect normality,[13] we performed additional tests (i.e. outlier tests) and/or used graphical methods[14] to understand the reasons for deviation from normality. Appendix III displays one of these graphical methods, the box–plot graphs. We observed that there are two main reasons of non-normality: (1) the presence of outliers in the sample (e.g. investments (€/M € of GDP) in Belgium in the group “cost-based regulation models”) and (2) the sensitivity of the observations to the normalization factors (i.e. populations that were normally distributed when normalized with GDP and non-normally distributed when normalized with population).

Overall, the results of normality tests and the graphical methods used, provided limited evidence in support of the assumption of normality, thus creating high uncertainty regarding the choice of the appropriate hypothesis test. Due to the lack of confidence regarding the existence of normality, it was decided to carry out two different analyses, one with a parametric Student's T-test and a second one with a non-parametric U-test.

4.2.2. *Independent observations*

All the samples utilized in the analysis satisfy the assumption of independence, since none of the observations in one group is in any way related to the observations in the other groups (Coladarci et al., 2014). Undoubtedly, the investments in country i cannot overlap (be common) with the investments in country u, thus a portion of investment χ_i of country i cannot be present in more than one group in any of the regulatory factors analysis. With respect to the multinational projects, whenever their budget is split between different countries, we consider the investment decisions in one country independent of the investment decisions in another country. Hence the participation of countries in common projects

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[12] Kolmogorov–Smirnov has poor power to detect non-normality and as D'Agostino and Stephens (1986) suggest the test is nowadays of historical interest only.

[13] Either because of the small size samples (n. obs. < 8) or because of other reasons.

[14] The graphical methods include box plots, quantile–quantile plots (Q–Q plots) and histograms.

do not follow a certain pattern.

4.2.3. Homogeneity of variances

To check for heteroscedasticity among the samples, we chose to apply Levene's test, against the alternative of Bartlett's test. Levene's test is widely considered powerful and robust, and is less sensitive to departures from normality as compared to the Bartlett's test. The literature suggests its use when the underlying data are not normally distributed and the variances are in fact equal, as may be the case in the current analysis.

The second Table of the Appendix II reports the results of Levene's tests for all of our study samples. With one exception, Levene's test verified homoscedasticity in the samples ($p > 5\%$). In particular, the only reported inequality of variances concerned the “innovation-stimulus mechanisms” analysis (the case of GDP normalization), where p-values were equal to 4%. In this case, where heteroscedasticity was detected, we apply an adaptation of the Student's T-test, namely Welch's T-test, which is more reliable when two samples have unequal variances and/or unequal sample sizes.

4.3. Statistical hypothesis testing

In order to perform statistical testing of our hypotheses and check for differences in means among the country groups in term of investments, both parametric and non-parametric statistical methods were used. As illustrated in section 4.2.1, the samples do not provide enough evidence of distribution. For this reason, two different tests were employed: a Student's T-test (or independent T-test) was used whenever normality was found and a Mann–Witney's U-test was used whenever normality was violated (non–normality). Finally, in the case of normality, a Welch's T-test was used whenever an inequality of variances was detected.

For all statistical analyses, where a comparison between the means of two distinct populations was performed, a one-tailed test with two hypotheses was considered:

$$-H_0 : \mu_1 - \mu_2 = 0 \Leftrightarrow \mu_1 = \mu_2 \quad \text{(null hypothesis)}$$

$$-H_1 : \mu_1 - \mu_2 > 0 \Leftrightarrow \mu_1 > \mu_2 \quad \text{(alternative hypothesis)}$$

Under the null hypothesis, the mean values reflecting SG investments for the groups of countries are not affected by the divergence of values of the regulatory factor, thus μ_1 equals μ_2. This study considers a level of statistical significance equal to 0.10 ($\alpha = 10\%$) for all tests carried out. This implies that a p-value greater than 0.10 is statistically insignificant and a p-value of less than 0.01 is highly statistically significant. As a general rule, the smaller the p-value, the stronger is the evidence against the null hypothesis.

4.3.1. Results for “distribution-sector concentration”

Table 3a presents the mean values for SG investments based on the independent variable representing distribution-sector concentration. The groups are denoted by *H* for high concentration, *M* for medium concentration, and *L* for low concentration and their respective sample means are denoted by $\overline{X}_H$, $\overline{X}_M$, and $\overline{X}_L$. On average, SG investment is greater in countries with low concentration than in countries with medium and high for both cases of normalization. Furthermore, SG investment is less in high concentration countries overall.

To assess the strength of the evidence, a p-value was calculated to assess whether the sample results were likely to have occurred. Indeed, with regard to per-capita normalization of investments, both the T and U tests' p-values provided strong evidence for rejecting the null hypothesis concerning the equality of average investments. Thus, it can be inferred that countries with low concentrated markets invest more than the ones with medium and high concentrated markets, as the p-values are generally low and equal to 0% and 1%.

Comparing the investments in medium and high concentration markets, the p-values for both T and U tests are relatively high and equal to 21% and 40%, implying that the two values are not statistically different. The overall results indicate that low distribution-sector concentration, where many DSOs satisfy the total demand for distribution of electricity, is statistically and positively correlated to the level of investments.

However, when investments were normalized with the GDP, the p-values for both tests provided weak evidence for rejecting the null hypothesis for most of the comparisons. Comparing mean values for the low and medium concentration groups, the T and U tests provide p-values equal to 6% and 9% respectively. Similarly, in the comparison of low and high concentration groups, the p-values are equal to 10%, providing some relatively weak evidence to reject the alternative hypothesis.

The overall results suggest a positive correlation between low concentrated markets and the level of SG investments. Several reasons may explain this result. Lopes Ferreira et al. (2011) have shown that the less concentrated markets have a higher deployment of distributed generation (DG). Arguably, the increased penetration of DG makes more urgent the need for “smartening” the network, thus inducing higher investments. Another explanation may be the relatively “small” size of DSOs in these counties. For instance, Ruester et al. (2014) argue that “small” DSOs can jointly invest in ICT or electric vehicles (EV) infrastructure, exploiting synergies and reducing each DSO's contribution to the cost of setting up such new and costly infrastructure. A good example is the “RegModHarz” project in Germany, where seven individual DSOs are collaborating to develop tools, infrastructures, and strategies to supply the Harz region with electricity generation coming solely from renewable sources.

4.3.2. Results for “regulatory-mechanisms”

Table 3b presents the mean values for SG investments based on the independent variable representing regulatory-mechanism. The groups are denoted by *C* for cost-based model, *H* for hybrid model, and *I* for incentive-based and their respective sample means are denoted by $\overline{X}_C$, $\overline{X}_H$ and $\overline{X}_I$. On average, SG investment is greater in countries applying hybrid models than in countries applying cost-based or incentive-based models.

For both cases of normalisation and for the majority of mean comparisons, the T and U tests' p-values are high enough and far greater than the standard 10% level of significance. Nevertheless, there are two exceptions when the investments are normalised with the GDP factor. The first concerns the mean comparison between *I* and *C* groups, where the p-value is equal to 4% in the U-test (in the T test the results is close to significant value too, with a p-value = 11%). This result suggests that incentive-based regulation may promote SG investments more effectively than cost-based regulation, supporting Marques et al. (2014)'s argument in that cost-based regulatory frameworks may not spur investments in technologies such as SG. Conversely, incentive regulation that allows investors to keep part of the gains realized from cost reductions may prove more effective in prompting SG investments (Marques et al., 2014). In the second case, we find weak evidence that countries with hybrid models motivate investments more than countries with cost-based schemes, as the p-value equals 7%. Marques et al. (2014) provide a conceivable explanation in that the more SG decrease costs, the more incentive regulation is effective on promoting “smart” technologies and the less cost-based regulation is effective.

Table 3a
Average investment in Smart Grids by distribution-sector concentration.

Distribution-sector concentration												
	High (H)		Medium (M)		Low (L)		P-value T-test			P-value U-test		
	$\overline{X}_H$	n_H	$\overline{X}_M$	n_C	$\overline{X}_L$	n_C	μ_L vs μ_M	μ_M vs μ_H	μ_L vs μ_H	μ_L vs μ_M	μ_M vs μ_H	μ_L vs μ_H
€/Capita	2.02	7	2.89	15	8.30	8	***	-	**	***	-	***
€/M€ of GDP	103.9	7	120.2	15	206.0	8	*	-	*	*	-	*

Note: $^{*}p \le 0.1$, $^{**}p \le 0.05$, $^{***}p \le 0.01$.

Table 3b
Average investment in Smart Grids by regulatory-mechanism.

Regulatory-mechanisms												
	Cost (C)		Hybrid (H)		Incentive (I)		P-value T-test			P-value U-test		
	$\overline{X}_C$	n_C	$\overline{X}_H$	n_H	$\overline{X}_I$	n_I	μ_H vs μ_C	μ_H vs μ_I	μ_I vs μ_C	μ_H vs μ_C	μ_H vs μ_I	μ_I vs μ_C
€/Capita	2.20	6	5.68	9	3.97	15	–	–	–	–	–	–
€/M€ of GDP	78.6	6	195.5	9	129.8	15	*	-$^{\wedge}$	-$^{\wedge}$	*	–	**

Note: *p $\le$ 0.1, **p $\le$ 0.05, ***p $\le$ 0.01, $^{\wedge}$p = 11%.

Table 3c
Average investment in Smart Grids by innovation-stimulus mechanism.

Innovation-stimulus mechanism						
	Yes (Y)		No (N)		P-value T-test	P-value U-test
	$\overline{X}_Y$	n_Y	$\overline{X}_N$	n_N	μ_Y vs μ_N	μ_Y vs μ_N
€/Capita	8.13	8	2.67	22	***	***
€/M € of GDP	259.6	8	95.5	22	***	***

Note: $^{*}p \le 0.1$, $^{**}p \le 0.05$, $^{***}p \le 0.01$.

In general, the lack of statistical significance in the majority of comparisons, as shown in Table 3b, may indicate the relatively low importance of regulatory incentives for cost efficiency in the decision to undertake substantial investments in SG. Indeed, other features of the regulatory models, such as the WACC, may be more important than cost-efficiency incentives considered here in terms of, affecting SG investments.

4.3.3. Results for "innovation-stimulus mechanisms"

Table 3c presents the mean values for SG investments based on the independent variable representing innovation-stimulus incentives. The groups are denoted by *Y* for countries where incentives are provided (in terms of both extra WACC and revenue adjustments) and *N* for the group of countries with no specialized innovation incentives. The groups' respective sample means are denoted by $\overline{X}_Y$ and $\overline{X}_N$. On average, we find more SG investment in countries where an incentive mechanism is applied than in countries where there are no specialized incentives for innovation investment.

For both cases of normalisation, the p-values are relatively low (less than 1%). Thus the findings provide strong evidence against rejecting the null hypothesis. As expected, the level of SG investments is greater when specialized incentives are provided to DSOs for the implementation of innovative projects. Both the mean differences and the low p-values suggest the use of incentive mechanisms by NERs to trigger the SG investments.

Still, a further examination should be performed for understanding the effect of an extra WACC versus the effect of an adjusted revenue mechanism on the level of SG investments. Due to the fact that only two countries apply the extra WAAC incentive mechanism, the current study does not include such an analysis. This type of analysis could reveal interesting results since the two mechanisms vary to a significant degree and are applied under different market conditions. In situations with large number of DSOs and a tradition of competitive markets, as in the UK, incentives are allocated on the basis of tendering procedures that allow DSOs to compete for resources on the implementation of innovative investment projects. In smaller markets with a dominant DSO, as in Portugal, the regulator's role is necessarily more direct in terms of negotiating incentives and monitoring outcomes (Crispim et al., 2014).

5. Conclusions

This paper reports our analysis of the interplay between key market and regulatory factors and SG investments in Europe. After reviewing the European regulatory status for SG developments, we analyse the effect of three discrete market and regulatory factors on the level of SG Investment. The transformation towards a smarter electricity system will require substantial investments, especially for the implementation of SG pilot projects. Significant investment needs suggest consideration of regulatory reforms to stimulate innovation. In this context, our study provides evidence of which market and regulatory factors appear to be effective in terms of enhancing incentives for SG deployment.

First, less concentrated distribution markets are expected to effectively induce investment-incentives for the implementation of SG pilot projects. Our results show that in countries where the market concentration ratio is low the DSOs invest much more on average than in countries where the ratio is high: the investment in SG averaged €206 per million Euros of GDP in the former countries as compared to €104 per million Euros of GDP in the latter. Prospective regulatory reforms may introduce horizontal unbundling processes in the countries where high concentrated markets still exist. However this type of reform may be subject to strong oppositions by DSOs or other energy stakeholders, especially in cases where historic, geographic, socio-political, and economic conditions favour concentrated markets. Second, the analysis provides evidence that regulatory schemes could sustain more incentive-based outputs. As highlighted in the analysis, incentive-based regulation may spur the SG innovation and corresponding investment. Indeed, under incentive-based regulation, investments averaged €130 per million Euros of GDP as compared to €78.6 per million Euros of GDP in countries with cost-based regulation. Similarly, a hybrid model could also be effective in providing investment-incentives for SG, but apparently not as powerful as an incentive-based scheme. Third, the analysis shows that the adoption of innovation-stimulus mechanisms by regulation (such as the adoption of an extra WACC or adjusted revenues) is rather successful in promoting SG investments. Indeed, investments averaged €260 per million Euros of GDP where NERs have adopted specific incentives as compared to €95.5 per million Euros of GDP where incentives have not been implemented. As expected, the introduction of incentive mechanisms stimulates DSO engagement in innovative SG projects and thus, increases the corresponding investments. Regulatory reforms should consider the integration of innovation-stimulus incentives.

The analysis performed is subject to certain limitations. First, the current analysis is based on the current status of market and regulatory factors and SG investments across European countries, and thus can be considered valid for a short-term horizon. Second, the test results pointed out the sensitivity of the analysis to the factors employed for the normalization of SG investments. Future work could also incorporate normalizing factors for technical concerns, such as installed power capacity (TW), electricity consumption (TWh), and the length of the electricity grid (km). Second, a longer time series of data would allow for more sophisticated empirical analysis. Third, due to the lack of accurate data about the precise contribution of DSOs to the budget of SG projects, we use the overall budget of SG project at the country level. Further research could use the DSOs' contribution to SG projects as the dependent variable. Fourth, the study does not take into account issues of complementarity and substitution between distribution and transmission networks, as well as polar viewpoints about future investment in these sectors. One view is that SG capabilities will negate the need for new transmission lines. Another is that Europe will need a vastly expanded transmission grid to enable large-scale RES integration, improve energy security, and allow pan-European energy trading in wholesale markets. Finally, our analysis is confined to Europe but could be extended worldwide to consider the experiences of more countries as they adopt regulatory reforms related to SG innovation and investment.

Disclaimer

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Appendix I. Normalized data

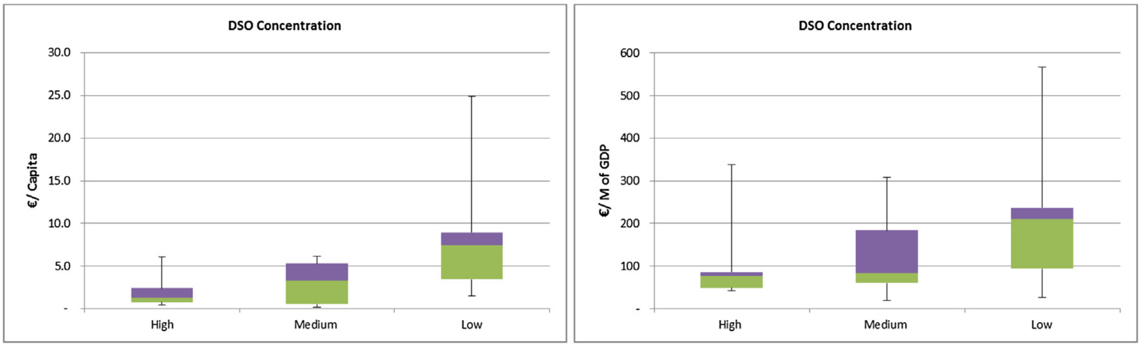
Country	Country code	Average population *(M years 2008–2013)*	Average GDP *(M€ years 2008–2013)*	Actual investment *(M€ years 2008–2013)*	Normalized investment *(€/capita)*	Normalized investment *(€/M€ of GDP)*
Austria	AT	8.37	303,468	58.81	7.03	193.80
Belgium	BE	10.92	372,307	85.06	7.77	228.46
Bulgaria	BG	7.40	38,562	2.19	0.30	56.77
Switzerland	CH	7.82	456,694	11.96	1.53	26.19
Cyprus	CY	0.83	18,879	1.05	1.27	55.49
Czech Republic	CZ	10.46	157,917	34.66	3.31	219.48
Germany	DE	81.44	2,641,563	288.44	3.54	109.19
Denmark	DK	5.54	243,770	138.00	24.89	566.12
Estonia	EE	1.33	16,356	1.06	0.80	64.73
Greece	EL	11.14	215,022	16.39	1.49	76.20
Spain	ES	46.43	1,075,940	187.81	4.06	174.56
Finland	FI	5.36	193,416	47.05	8.77	243.26
France	FR	62.91	2,032,896	388.59	6.18	191.15
Croatia	HR	4.29	45,071	1.92	0.45	42.64
Hungary	HU	9.99	99,654	8.25	0.83	82.83
Ireland	IE	4.55	173,084	15.40	3.35	88.99
Italy	IT	59.21	1,612,622	220.50	3.72	136.73
Lithuania	LT	3.09	31,192	2.63	0.85	84.32
Luxembourg	LU	0.51	40,750	2.78	5.47	68.33
Latvia	LV	2.10	21,152	0.57	0.27	26.77
Malta	MT	0.41	6761	0.29	0.70	42.80
Netherlands	NL	16.61	635,230	98.70	5.93	155.37
Norway	NO	4.89	344,469	16.22	3.27	47.08
Poland	PL	38.08	366,247	7.03	0.18	19.21
Portugal	PT	10.55	174,702	53.54	5.11	306.46
Romania	RO	20.28	133,491	3.68	0.18	27.55
Sweden	SE	9.37	382,617	89.87	9.59	234.89
Slovenia	SI	2.04	36,559	12.35	6.05	337.71
Slovakia	SK	5.39	68,770	4.73	0.88	68.75
United Kingdom	UK	62.76	1,885,004	383.00	6.10	203.18

Appendix II. Shapiro–Wilk and Levene's tests results

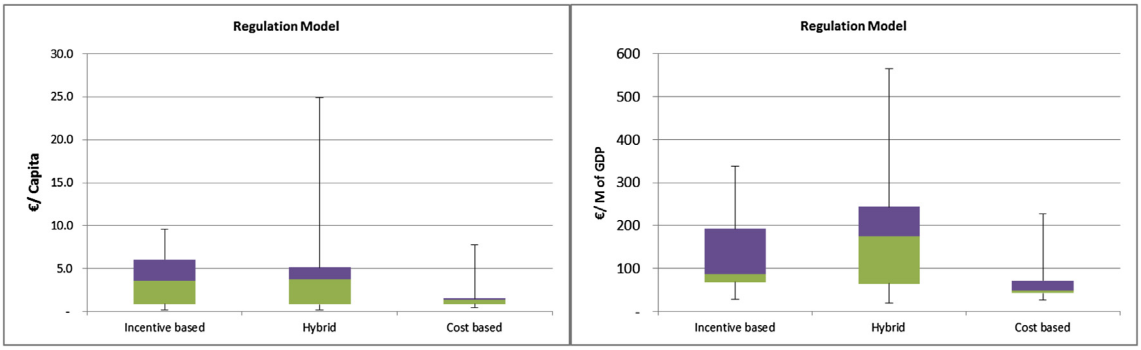
Factor	Distribution-sector concentration			Regulatory-mechanisms			Innovation-stimulus mechanism	
Groups	High	Medium	Low	Incentive-based	Hybrid	Cost-based	No Incentives	Specialized Incentives
€/Capita	0.03	0.01	0.01	0.15	0.00	0.00	0.00	0.00
€/Mof GDP	0.00	0.16	0.10	0.07	0.21	0.00	0.00	0.35

Regulatory factor	€/Capita			€/M € of GDP			α
	Means	Medians	Trimmed	Means	Medians	Trimmed	
Distribution-sector concentration	10%	12%	10%	43%	39%	43%	5%
Regulatory-mechanisms	14%	35%	14%	12%	17%	12%	5%
Innovation-stimulus mechanisms	9%	33%	9%	4%	9%	4%	5%

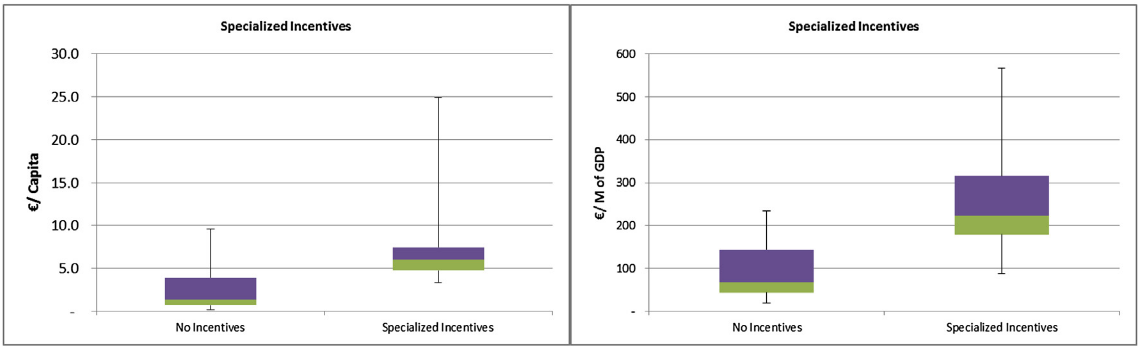
Appendix III. Box-plots



Distribution-sector concentration.



Regulatory-mechanisms.



Innovation-stimulus mechanisms.

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