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Public policies for smart grids in Brazil

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ABSTRACT

The evolution of existing electricity grids to smart grids is aimed at accommodating increasing shares of renewable generation thus contributing for the de-carbonization of economy, offering more diversified services to consumers, enhancing different types of markets (energy, capacity, ancillary services) and improving the system's overall efficiency. As the economic characteristics of the electricity sector tend to discourage investments in smart grids, many countries have adopted incentive policies to foster the deployment of new technologies, which vary according to the particular characteristics of each country. Therefore, the design of specific public policies for Brazil must consider not only the motivations involved, but also the existing challenges for the implementation of smart grids and the socio-economic context. Moreover, the relevance of the proposed policies can be seen from different perspectives. This justifies the need to elicit information from multiple stakeholders for decision support purposes. This paper presents and assesses a set of policies identified by different stakeholders as having a potential to foster the development of smart grids in Brazil. The methodology to shape this set of policies consisted of a thorough literature review of international experiences, combined with meetings with experts in several domains. Then, these policies were assessed by applying a Delphi questionnaire aiming at measuring their effectiveness in fulfilling the objectives associated with investments in smart grids. A first conclusion is that all policies were assessed as having a positive impact taking into account each of the objectives, differing only in the priority to be assigned to each one. The policies that were considered more relevant were: "Incentive Policies for Promoting Demand-Side Management, Distributed Generation and Storage", "Regulatory Changes to Foster Innovation in the Energy Sector" and "Regulation of New Business Models". Among the policies with the worst scores, "Mandatory Rollout of Smart Meters" and "Establishing Quality Standards for the Telecommunications Industry" were ranked as the two lower-ranked policies, i.e., they were assigned lower priority under all objectives.

1. Introduction

The evolution of existing electricity grids to smart grids strongly relying on information and communication technologies (ICT) is expected to contribute to improving the system's overall efficiency. This includes enhancing quality of service, decreasing technical and non-technical losses, saving operational costs, facilitating the penetration of dispersed generation based on renewable sources and deferring investments on generation and network capacity, while empowering consumers and allowing new business models to emerge (e.g., aggregators). Smart grids will allow innovative demand-side management benefitting from dynamic electricity pricing, diffusion of electric mobility, and the introduction of electricity storage systems [1]. However, the economic characteristics of the electricity sector, particularly with respect to the regulatory framework and traditional business models, tend to discourage investments in smart grids [2–5]. In this context, many countries have adopted incentive policies to foster the deployment of smart grids [6,7].

It is noticeable that these policies vary, depending on the specific characteristics of each country [8,9]. Therefore, the design of specific

Abbreviations: ANEEL, Brazilian regulator of the electrical energy sector; CAPEX, Capital expenditures; EU, European Union; ICT, Information and communication technologies; MCDA, Multi-criteria decision analysis/aid; OFGEM, Office of Gas and Electricity Markets; OPEX, Operational expenditures; RIIO, Revenue = Incentives + Innovation + Outputs; V2G, Vehicle-to-grid

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public policies for Brazil must consider not only the motivations involved, but also the existing challenges for the implementation of smart grids and the socio-economic context of the country. The pursuit of efficiency gains and the improvement of the quality of service offered by the electrical system are the main drivers for the development of smart grids in Brazil. The relevance of the proposed policies related to the development of smart grids can be seen from different perspectives, which justifies the importance of eliciting information from multiple stakeholders for decision support purposes.

The aim of this paper is to present and assess a set of policies identified by different stakeholders as having a potential major contribution for the development of smart grids in Brazil. The methodology to shape this set of policies consisted of a thorough literature review of international experiences, combined with meetings with experts in several domains (companies and entities in the electricity sector, government bodies including regulators, and academia), in order to characterize the current situation and the development prospects of smart grids in Brazil. An assessment of these policies was made by applying a Delphi questionnaire [10–12], with the purpose of measuring how effective these policies are in fulfilling the objectives associated with investments in smart grids.

This introduction provided the context and motivation of the study. Section 2 examines the need of public policies for the development of smart grids due to the economic characteristics of the electricity sector. Section 3 presents the set of public policies. Section 4 describes the application of the Delphi method to elicit information from stakeholders. The main results obtained are presented in Section 5 and discussed in Section 6. Finally, some conclusions and implications are drawn in Section 7.

2. Public policies for smart grids

It has been recognized that conventional grids are inadequate to meet the demands of the electrical system in the near future, due to concurrent needs: increasing the penetration of renewable sources, deploying micro-generation and storage systems, implementing active demand-side management mechanisms, and accounting for the expected growth of electric mobility including electric vehicles operation in vehicle-to-grid mode [13–15]. The dissemination of distributed generation based on renewable and intermittent sources may result in bidirectional energy flows in the grid and the growing share of electric vehicles imposes new technical challenges. Active demand control, storage systems and electric vehicles may increase problems in the grid. As a result, a *smarter* grid requires further control and automation mechanisms, including the deployment of smart metering systems at the customers' premises. This emerging technological paradigm, in which consumers will play a more prominent role through demand response mechanisms, needs to be supported by appropriate public policies, including regulatory ones, promoting investments on technological innovations in the grid [16–19].

Several technical and economic characteristics of the electricity sector must be taken into account when discussing the implementation of smart grids. Besides being an industry that requires instantaneous balance between demand and supply, the electricity sector is a capital-intensive industry with a homogeneous product, almost inelastic demand and regulated (access to grid) tariffs due to the existence of natural monopolies in the network businesses [20,21]. These characteristics do not favor the occurrence of innovation processes endogenously to the dynamics of the sector. Innovation generally occurs because the firm obtains a new process or product that allows it to increase profits for a certain period of time [22]. Given that electricity is a homogeneous good, product differentiation is limited. Moreover, new technologies tend to have initially a higher cost than the conventional alternatives. As a result, the market conditions do not favor the diffusion of technologies, for instance those with lower environmental impact [23,24].

Whenever the innovation process is hindered by the industry's characteristics and/or the regulatory framework, it is appropriate to adopt public policies that mitigate barriers to innovation and therefore encourage economic agents to innovate. But in order to succeed, it is necessary to know the characteristics of those barriers and the typologies of policy instruments [25]. Policy makers should intervene only when the implementation of innovation policies is justifiable. In addition, the interaction of different interest groups and agents with government institutions is essential to the creation of a coalition of stakeholders supporting the emerging technologies [26].

The diffusion of new technologies in the electricity sector follows a process that begins with research and development activities aimed at solving technical problems and reducing costs. Considering the nature of these activities, stakes are high and results are highly uncertain. Then, in general, a demonstration stage follows, in which the new technology must prove its feasibility. Finally, there is the market development and commercial distribution stage. It is important to highlight the value of public policies throughout this process to fund research and development activities as well as demonstration activities, and also to support the penetration of new technologies in the market [27]. In this context, Kiss and Neji [28] recognize the important role of government intervention in the innovation process, whose success depends on the public policy strategies adopted. More specifically, Sung and Song [26] emphasize the central role of government in technology development in the field of renewable energy.

In the case of smart grids, the scope of research and development projects, as well as demonstration projects, is quite broad. We note the relevance of carrying out projects related to grid automation, large-scale integration of renewable energy, electric vehicles, demand-side management as well as exploratory pilot projects related to technological solutions like smart metering or regulatory changes like dynamic tariffs [29,30]. Since a technological transition is a process that goes beyond the technological sphere, these projects must also include other variables, especially the issue of social acceptance [31]. For instance, it is quite important to develop studies that address the price elasticity of demand in order to gauge the real impacts that demand response measures have on the system. For this purpose, Toft et al. [32] suggest that research is needed to achieve a better understanding of what makes consumers accept or reject smart grid technologies in order to properly develop and effectively spread these new technologies and achieve the political goals envisaged.

Given that the electricity distribution is a natural monopoly and heavily regulated [3,33], the peculiarities of the market diffusion of smart grids should be emphasized. The incentives to smart grids tend to be more associated with changes in the regulatory setting than the formulation of public policies in a broader sense. In contrast to conventional grids, smart grids are characterized by a higher proportion of operating costs relative to the amount of capital invested. Therefore traditional regulatory models, which are predominantly cost service or incentive regulation, do not encourage investments in smart grids, because they are focused on the asset base [3,34]. Namely, the economic and financial attractiveness of investments in the grid automation and the rollout of smart meters become questionable under most present regulatory frameworks. It is thus necessary to discuss the asset base remuneration, the tariff structure, the establishment of which activities remain regulated and which will be open to competition, the ownership of new tools (smart meters, charging stations for electric vehicles, big data, etc.) and the relationship between the distribution and transmission companies [35,36].

The relation between the electric power industry and the telecommunications industry is also important to the development of smart grids. Lin et al. [9] emphasize the need to adopt policies and regulations that remove barriers to investment in ICT thus allowing the exploitation of the full potential in the value chain as a precondition for the development of smart grids. Erlinghagen and Markard [37], in turn, consider ICT firms as potential catalysts for changes in the electricity sector.

In summary, the technological transition to smart grids is not expected to occur endogenously to the dynamics of the electricity sector. As a result, the implementation of incentive policies and changes in the regulatory framework are needed for the development of smart grids, as can also be seen from the international experience. The definition of those policies must consider the particularities of each country and the interests of different stakeholders.

3. Public policies for smart grids development

The previous section concluded that the development of smart grids in Brazil requires adequate policy instruments and regulatory measures. For this purpose, a set of eight public policies for the development of smart grids in Brazil was defined, based on the analysis of the current status, the expected prospects and implementation challenges [38], the discussion with stakeholders in several sectors and the study of the international experience of incentive policies for smart grids [9,18,39–41]. The proposed policies, briefly described in the next subsections, are quite varied in their contents and scope, not being mutually exclusive.

3.1. Mandatory rollout of smart meters

Considering that the real-time monitoring of all energy flows requires a smart metering system, the installation of smart meters is an important action to deal with the challenges associated with the implementation of demand-side management activities and diffusion of distributed generation and energy storage. Smart metering can thus contribute to a more efficient and reliable electrical system. In the context of establishing goals for the development of smart grids, the mandatory rollout of smart meters is a measure commonly enacted worldwide. As an illustration, the EU Directive [42], which encourages the optimal usage of energy resources, emphasizes the importance of adopting smart metering systems. This directive makes clear that one of the goals associated with the implementation of intelligent metering systems is assisting the active participation of consumers in the electricity supply market. In the same direction, it is possible to mention the rollout of smart meters implemented in California [43].

However, although the installation of smart meters has the potential to improve quality of service, operational costs and global system operation, their deployment brings new technical, regulatory, economic and social challenges. Thereby, the interests of different stakeholders must be considered. The issue of data privacy is very controversial and in some cases there is opposition from consumers to the installation of these meters [44]. To mitigate this drawback, the Netherlands and California granted the consumer the right to refuse the installation of the smart meter [45]. At the same time, the property of vast amount of data generated, and the consequent possibility to exploit them commercially, is a topic still under discussion. The tendency in the European Union is to classify these big data as a public good.

The nub of the question of the viability of the rollout of smart meters is associated with investment costs. The way costs and benefits are shared among different stakeholders takes on enormous importance. For instance, although the European Union has set a rollout target for each country (at least 80% of the metering points), this target should be pursued only in cases where a positive cost-benefit analysis justifies it [46]. The result of the analysis varies from country to country depending on the electrical system and the market structures, or even the anticipated consumers' behavior [46,47]. In Italy, for example, the rollout was implemented before any regulations about smart meters, being justified by the need to reduce operating costs and non-technical losses. In France, meanwhile, the ongoing rollout was deemed feasible by the expected reduction in operating costs. In Germany, however, the cost-benefit analysis indicated a negative result [48].

Based on the international experience, the adoption of a mandatory rollout of smart meters in Brazil is a policy that should be examined. In addition, Brazil has specific drivers associated with the rollout of smart meters. In particular, non-technical losses are significant in some regions of Brazil. Although smart meters are not able to reduce these losses by themselves, they allow to accurately identify their location and therefore support the adoption of effective countermeasures. Other drivers of smart meter diffusion in Brazil are the adoption of dynamic electricity tariff schemes, real-time monitoring of the load, and the necessity to deal with bidirectional energy flows to/from prosumers. The installation of these meters should be done by the distribution companies and the costs passed on to the final consumer through a tariff scheme. Considering the high number of distribution companies in Brazil, the option for a mandatory rollout would allow exploiting economies of scale.

3.2. Regulatory changes to foster innovation in the electricity sector

The implementation of smart grids requires substantial investments, especially in distribution networks. These capital expenditures are associated with the need to replace existing assets, the deployment of new control and automation devices and the provision of information and communication infrastructure. Since electricity distribution is a regulated activity, the attractiveness of these investments is associated with the current regulatory framework [49].

In general, the current regulatory framework does not foster innovation in the electricity sector. Although price-cap models are based on the logic of incentive regulation in order to encourage efficiency, in practice the remuneration on the asset base continues to be pre-defined and commonly there is no incentive to adopt more efficient technologies [39,50]. Furthermore, these new technologies may be unfeasible in economic terms. This happens because, in general, the current regulatory frameworks do not recognize that investment or do not remunerate it adequately, especially with regard to technologies characterized by a higher proportion of operational expenditures (OPEX) in relation to capital expenditures (CAPEX) in their cost structure.

Regulatory changes are therefore necessary to foster investment in smart grids. There should be an effective transformation of the regulatory logic with the emergence of output-based models over traditional input-based models. The choice of output-based models lies on the premise that distribution companies have more capacity to scale the required investments and, therefore, it is appropriate to grant autonomy to these companies. Thus, the regulator's role should be to establish minimum requirements for inter-operability, reliability and quality of service to be met by distribution companies. Companies are encouraged to make investments considering that the regulator establishes incentives and penalties. Such models create conditions for effective renewal and modernization of assets [39,50]. Nevertheless, it is important to develop methodologies to remunerate properly technologies with a higher proportion of OPEX in their cost structure.

As an illustration of possible regulatory developments, recent changes in UK regulation with the introduction of RIIO framework (Revenue = Incentives + Innovation + Outputs) are quite representative. In RIIO, the regulator (OFGEM) reshaped the current price-cap model by inserting elements that induce innovation [40]. As an output-based incentive scheme, the RIIO framework not only gives to the British utilities autonomy to make investment decisions, but it also provides incentives for companies to opt for more efficient technologies and, at the same time, implement innovations.

Therefore, in order to develop smart grids through the modernization of the Brazilian networks, the adoption of a regulatory model based on incentives is recommended. Thus, the distribution companies, even if subjected to targets, will have autonomy to decide which investments they should carry out, so that more efficient technologies can be adopted.

3.3. Improvement of research & development and demonstration projects

Although some Research & Development (R&D) and demonstration projects in Brazil have been focused on smart grids, they strongly depend on the financial resources of the R&D program of the regulator of the electrical energy sector (ANEEL) and, to some extent, of Inova Energy Program [51]. As a result, the coverage and dissemination of projects tends to be limited. Meanwhile, industry is reducing its involvement in the technological development process. Thus, there is evidence that R&D projects are not being sufficiently able to encourage the creation and diffusion of technological innovations. In this context, it is necessary a greater coordination/integration of different projects and industry involvement, with an emphasis on projects with higher levels of technological maturity. Furthermore, it is appropriate to build a shared knowledge base to widen diffusion of project results.

As an illustration of the importance of implementing projects with higher levels of technological maturity, in the European Union there is greater investment in smart grid demonstration projects than in R&D projects. This shows the importance of smart grid projects not remaining restricted to the pilot/experimental stage, but effectively acting as inducers of investments in grid modernization through the adoption of technological innovations [52].

At the same time, incentives are important to foster projects with higher levels of risk. For this aim, the adoption of a risk premium on the rate of return of such projects is a relevant strategy [49]. This type of guideline has been adopted in some countries; for example, in Italy the regulation enables pilot projects to earn a 2% risk premium over 12 years [40].

Additionally, ANEEL's energy efficiency program can fund smart grid projects and the available resources can also be used in applied projects. Such a strategy would be relevant to encourage the effective implementation of technological innovations in the electricity sector. More specifically, the success of the pilot projects is not sufficient; it also necessary to create conditions for the diffusion of new systems and equipment. Finally, it is desirable that the projects include the qualification of specialized workforce.

3.4. Incentive policies for promoting demand-side management, distributed generation and storage

Although this article focuses on smart grids in a strict sense (smart metering systems and grid automation), there are related technologies/measures that represent a new paradigm [2]. This is characterized by the emergence of an electrical system consisting of distributed energy resources where consumers have a more active behavior and adopt demand-side management measures. The adoption of policies promoting the diffusion of these technologies/measures, as well as regulatory guidelines for this purpose, could induce the development of smart grids.

In this regard, the establishment of dynamic time-of-use tariffs is a key element for investments in the rollout of smart meters [53]. One of the main benefits of deploying smart meters is the possibility of implementing demand response programs, which are generally associated with signals conveyed by dynamic pricing models.

Although the investment in micro-generation units does not depend on the existence of a smart grid, the effective diffusion of a system characterized by the massive presence of distributed energy resources, while guaranteeing the reliability and quality of the power supply, requires the implementation of smart grids able to monitor all electricity flows in real-time [54]. The significant presence of intermittent generation sources in the generation matrix emphasizes the need of implementing demand-side management, in a paradigm shift from "supply follows load" to "load follows supply" strategies [55].

Policies for promoting distributed generation have already been established worldwide, especially in developed countries [56,57]. For instance, the feed-in tariffs implemented in several EU member countries have the aim of encouraging investment in micro-generation. In Brazil there are also steps in this direction, such as ANEEL's Normative Resolution No. 482 [58,59], which deals with the regulation of micro- and mini-generation. In any case, tax exemptions and special lines of credit are important incentives for distributed energy resources.

It is noteworthy that, in contrast to micro-generation, there is still much uncertainty about the future concerning the diffusion of storage technologies at the consumer level. Therefore, incentive policies assume greater importance. Electric vehicles deserve particular attention, possibly representing the most immediate option for energy storage through the operation of its battery in vehicle-to-grid (V2G) mode.

The adoption of incentive policies for promoting demand-side management, distributed generation and energy storage are linked to the regulatory framework in the distribution segment (cf. 3.2), given the need to ensure that the diffusion of these technologies does not compromise the economic/financial viability of electricity distribution companies.

3.5. Establishing quality standards for the telecommunications industry

Given that smart grids rely heavily on ICT, the telecommunications network quality has a large importance for their development; that is, a reliable telecommunications network is required for the effective implementation of smart grids [60].

The Brazilian telecommunication network is precarious. Given that telecom operators have been unable to provide services with the required performance, the electricity distribution companies have been constructing their own telecommunication networks for their projects. However, adopting this strategy entails a significant increase in costs for smart grid projects, considering that these investments may represent between 21% and 36% of total spending [61].

For this purpose, a better regulation of the relations between the electricity and the telecommunications sectors is necessary. The availability of an efficient telecommunications network would eliminate the need to carry out substantial investments in the implementation of custom-built networks. Furthermore, telecommunication networks belonging to electricity distribution companies tend to be underused because these companies are barred from exploiting telecommunication services. On the other hand, meeting the telecommunications needs for smart grids is a business opportunity for telecommunication companies.

Therefore, considering that the establishment of quality standards for telecommunications operators would help reducing the need for investment by the electricity companies, it is necessary to examine in greater detail the adoption of this policy. This policy is especially important since it makes the rollout of smart meters by the electricity distribution companies more feasible, due to the lower expenditure required for the implementation of smart metering systems.

3.6. Regulation of new business models

As pointed out by Sioshansi [62], the changes sought for the electricity sector are not consistent with the traditional utility business model; therefore, it is necessary to regulate new business models. In general, the emergence of a paradigm characterized by the presence of distributed energy resources, where all energy flows are monitored in real time, leads to new business opportunities to be exploited. These opportunities range from new products and systems to the exploration of new solutions and services. It is also necessary to regulate the activities of new agents, such as aggregators of demand-side flexibility that can participate in ancillary services markets. At the same time, issues related to the participation of distribution companies in unregulated activities should be addressed.

The importance of new business models stems from the observation that the creation of value for consumers, and the consequent profit taking by entrepreneurs, is essential for the transition to smart and sustainable electrical systems. Therefore, it is not enough to know the technical characteristics of smart grids and related technologies; attention should also be paid to the concerns of firms and consumers when transacting goods and services related to smart grids [63].

From the perspective of the companies in the electricity sector, the consequences of the expansion of smart grids and distributed energy resources are ambiguous since it may be harmful to the traditional business model and at the same time may provide new business opportunities. On the one hand, the prospects of market reduction and entry of new agents constitute a threat for traditional firms in the electricity sector. At the same time, distribution companies may incur additional costs arising from new technologies. On the other hand, in addition to the possibility of reducing system costs due to efficiency gains, new opportunities arise, for example the integration of renewable resources, demand response programs, vehicle-to-grid operation and the exploitation of big data [64].

It is possible to foresee the appearance of new agents such as load aggregators and virtual power plants, as well as a more active role of energy efficiency service providers. The volume of available data will allow the design of services personalized to the needs of each consumer. The emergence of new agents and the permission for distribution companies to act in unregulated markets are trends already observed in countries where electricity sector transformations are ongoing. In short, the main issue is the creation of a regulatory framework that fosters new business models compatible with the emerging new technological paradigm.

3.7. Development plan for smart cities

In accordance with the need to meet the contemporary socio-economic demands without imposing major impacts on the environment, the concept of smart cities is gaining relevance. According to Calvillo et al. [65], smart cities can be defined as sustainable and efficient urban centers providing a high quality of life to their inhabitants through optimal integrated management of resources. Given the complexity and the importance of energy systems, the discussion about smart cities is associated with the search for efficient and sustainable energy solutions. As a result, it is apparent that the development of smart grids is a prerequisite for the development of smart cities.

However, since the concept of smart cities promotes the rational, integrated and sustainable use of all resources, there is an evident need to adopt new paradigms in other infrastructure industries (roads, water, sanitation, public transportation, telecommunications, etc.), which should also become smart(er) through the ubiquitous use of ICT [66]. Therefore, the issue of sharing ICT infrastructures becomes particularly relevant.

In this context, the establishment of development plans for smart cities is a strategy with potential to encourage investment in smart grids, not just because smart grids are essential to smart cities but also to promote sharing of ICT infrastructures with other public service operators, thus reducing investment costs. In addition, these development plans will allow taking advantage of synergies between different services, for example, enhancing the combination of energy efficiency programs with stimulus plans to electric mobility in urban transportation.

3.8. National development policy for smart grid industry

The development of smart grids has the potential to provide economic benefits to the country provided that its domestic industry is capable of supplying the market. The potential to export goods and services related to smart grids technologies is an important driver for the development of smart grids, as can be seen in countries such as Germany and South Korea [67,68].

For this purpose, a set of financial incentives to the industrial development could be adopted, which would be gradually reduced with the level of industrial development attained. For instance, attractive financing conditions are very important for investment in industrial plants. In addition to financial incentives, it is also desirable to establish rules that encourage a higher level of R&D activity throughout the supply chain. These incentives should be focused on market niches where the country has greater endogenous competences (engineering, manufacturing, etc.).

Another important initiative in this setting is the establishment of partnerships with countries in more advanced stages in the development of smart grids. These agreements aim to exchange experiences and the trade of technologies already tested and approved internationally. It should be noted that this technology transfer may be conditional upon the adaptation of such technology to Brazilian specificities. It is also very important to establish trade agreements that allow Brazil to export equipment to markets in which it has competitive advantages, as well as the import of equipment that the domestic industry is not able to provide. In this context, it is important to establish norms, standards and interoperability compatible with the best international practices to enable Brazilian companies to compete in international markets.

4. Methodology for evaluating proposed policies

In order to assess the proposed public policies, a Delphi questionnaire was applied to a selected group of experts and stakeholders in the electricity sector. The main objective of the Delphi methodology in the framework of this study was to obtain the most reliable consensus of opinion by the group of experts and stakeholders. The method was applied through an iterative questionnaire, designed by the authors, applied in consecutive rounds until a satisfactory degree of consensus among respondents was obtained. This consensus represents a consolidation of the intuitive judgment of the group of experts [12]. Three features that eliminate the negative effects of group interactions and characterize the Delphi method [10,11]: respondents are anonymous to each other, results are presented statistically, and there is feedback after each evaluation round.

The first phase of the research comprised the identification of invited experts and the preparation of questionnaire 1. Regarding the choice of the participants, a set of 64 relevant experts in the electricity sector was identified, for which invitations were sent. At this stage, a major concern was diversifying the set of experts, extending the invitation to the areas of *knowledge* (academia and consulting), electricity companies and government. From the total of 64 experts invited, 35 responded to the first questionnaire and 28 responded to the second questionnaire.

Regarding the formulation of the questions contained in the questionnaire, the aim was to cover a comprehensive range of issues associated with the development of smart grids. Due to the wide variety of issues, a prior structuring was necessary to facilitate the assessment of potential incentive policies. For this purpose, from a set of issues originally listed as potential concerns and criteria for evaluation, a categorization was held aiming to propose a set of seven fundamental objectives in line with priorities for technological innovation in the energy sector: i) benefit the environment and human health; ii) enhance flexibility and capabilities of the system technological infrastructure; iii) ensure security of supply; iv) ensure openness, fairness, transparency and efficiency of markets; v) provide financial benefit to the agents involved; vi) provide economic and social benefit to the country; vii) ensure feasibility and promote the adoption of technological innovations [69].

From the seven fundamental objectives identified, eight questions were formulated. Questions 1–7 intended to collect the perceptions of the experts about the impact that each policy would have taking into account the objectives, in a range from −5 to +5. Fig. 1 (Appendix A) exemplifies how the question #1 of the first questionnaire was presented to participants. Questions 2–7 have the same structure of the first question, only varying the objectives considered in the assessment. Question #8 intended to elicit the perspective of the experts on the relative importance of each objective in a range from 0 to +5 (Fig. 2, Appendix A).

The questionnaire 2, according to the Delphi method, included some statistical information on the results obtained in the questionnaire 1. The research team chose to provide in each question the arithmetic mean and the standard deviation of the answers to questionnaire 1, as well as a chart summarizing this information. Fig. 3 (Appendix A) illustrates how this information was presented.

After the return of the second questionnaire, the research team concluded that the answers displayed a satisfactory degree of convergence and consensus, thus making a possible third round unnecessary. The presentation and analysis of results is made in Section 5.

Table 1
Question #1: Policies and objective of “benefit the environment and human health”.

Public policies	SD1	AM1	SD2	AM2	Ranking
1 – Mandatory Rollout of Smart Meters	1.87	1.53	1.42	1.39	8th
2 – Regulatory Changes to Foster Innovation in the Energy Sector	1.56	3.03	1.2	2.96	4th
3 – Improvement of Research & Development and Demonstration Projects	1.52	2.62	1.38	2.71	6th
4 – Incentive Policies for Promoting Demand-Side Management, Distributed Generation and Storage	1.56	3.54	1.15	3.86	1st
5 – Establishing Quality Standards for the Telecommunications Industry	1.78	2.5	1.8	2.19	7th
6 – Regulation of New Business Models	1.77	2.68	1.55	2.75	5th
7 – Development Plan for Smart Cities	1.41	3.8	1.52	3.79	2nd
8 – National Development Policy for Smart Grid Industry	1.61	3.38	1.4	3.11	3rd

Table 2
Question #2: Policies and objective of “enhance flexibility and capabilities of the system technological infrastructure”.

Public policies	SD1	AM1	SD2	AM2	Ranking
1 – Mandatory Rollout of Smart Meters	1.46	3.6	1.08	3.37	7th
2 – Regulatory Changes to Foster Innovation in the Energy Sector	1.24	3.86	0.71	4.04	1st
3 – Improvement of Research & Development and Demonstration Projects	1.17	3.63	0.98	3.48	6th
4 – Incentive Policies for Promoting Demand-Side Management, Distributed Generation and Storage	1.44	3.63	0.74	3.81	2nd
5 – Establishing Quality Standards for the Telecommunications Industry	1.53	3.12	1.35	2.85	8th
6 – Regulation of New Business Models	1.24	3.6	0.97	3.78	3rd
7 – Development Plan for Smart Cities	1.2	3.68	1.1	3.74	4th
8 – National Development Policy for Smart Grid Industry	1.45	3.66	0.93	3.63	5th

Table 3
Question #3: Policies and objective of “ensure security of supply”.

Public policies	SD1	AM1	SD2	AM2	Ranking
1 – Mandatory Rollout of Smart Meters	1.59	2.35	1.15	2.14	7th
2 – Regulatory Changes to Foster Innovation in the Energy Sector	1.34	3.29	0.90	3.29	2nd
3 – Improvement of Research & Development and Demonstration Projects	1.58	3.03	1.23	2.96	5th
4 – Incentive Policies for Promoting Demand-Side Management, Distributed Generation and Storage	1.44	3.83	0.94	4.07	1st
5 – Establishing Quality Standards for the Telecommunications Industry	1.55	2.72	1.32	2.04	8th
6 – Regulation of New Business Models	1.62	2.97	1.27	2.75	6th
7 – Development Plan for Smart Cities	1.51	3.06	1.37	3.11	3rd
8 – National Development Policy for Smart Grid Industry	1.58	3.09	1.23	3.11	4th

Table 4
Question #4: Policies and objective of “ensure openness, fairness, transparency and efficiency of markets”.

Public policies	SD1	AM1	SD2	AM2	Ranking
1 – Mandatory Rollout of Smart Meters	1.78	2.71	1.25	2.56	7th
2 – Regulatory Changes to Foster Innovation in the Energy Sector	1.36	3.49	0.88	3.57	3rd
3 – Improvement of Research & Development and Demonstration Projects	1.49	2.88	1.28	2.64	6th
4 – Incentive Policies for Promoting Demand-Side Management, Distributed Generation and Storage	1.36	3.49	0.93	3.86	1st
5 – Establishing Quality Standards for the Telecommunications Industry	1.77	2.52	1.49	2.15	8th
6 – Regulation of New Business Models	1.54	3.54	1.05	3.71	2nd
7 – Development Plan for Smart Cities	1.57	2.69	1.15	3.00	5th
8 – National Development Policy for Smart Grid Industry	1.36	2.91	1.12	3.07	4th

5. Results

This section presents the results of the Delphi method. Each table refers to a different question, presenting the question asked and the

Table 5
Question #5: Policies and objective of "provide financial benefit to the agents involved".

Public policies	SD1	AM1	SD2	AM2	Ranking
1 – Mandatory Rollout of Smart Meters	2.53	2.21	1.92	2.37	7th
2 – Regulatory Changes to Foster Innovation in the Energy Sector	1.6	2.97	0.93	3.25	3rd
3 – Improvement of Research & Development and Demonstration Projects	1.44	2.73	1.17	2.54	6th
4 – Incentive Policies for Promoting Demand-Side Management, Distributed Generation and Storage	2.14	3.12	1.24	3.25	4th
5 – Establishing Quality Standards for the Telecommunications Industry	2.00	1.85	1.37	1.59	8th
6 – Regulation of New Business Models	1.5	3.47	0.77	3.93	1st
7 – Development Plan for Smart Cities	1.74	2.65	1.25	2.93	5th
8 – National Development Policy for Smart Grid Industry	1.49	3.18	1.15	3.29	2nd

Table 6
Question #6: Policies and objective of "provide economic and social benefit to the country".

Public policies	SD1	AM1	SD2	AM2	Ranking
1 – Mandatory Rollout of Smart Meters	2.4	2.31	1.67	2.22	8th
2 – Regulatory Changes to Foster Innovation in the Energy Sector	1.31	3.74	1.00	3.75	4th
3 – Improvement of Research & Development and Demonstration Projects	1.40	3.54	1.26	3.46	6th
4 – Incentive Policies for Promoting Demand-Side Management, Distributed Generation and Storage	1.25	4.09	0.89	4.14	1st
5 – Establishing Quality Standards for the Telecommunications Industry	1.73	3.15	1.67	2.63	7th
6 – Regulation of New Business Models	1.43	3.69	0.88	3.79	3rd
7 – Development Plan for Smart Cities	1.38	3.74	1.08	3.71	5th
8 – National Development Policy for Smart Grid Industry	1.38	3.83	1.03	3.89	2nd

Table 7
Question #7: Policies and objective of "ensure feasibility and promote the adoption of technological innovations".

Public policies	SD1	AM1	SD2	AM2	Ranking
1 – Mandatory Rollout of Smart Meters	2.05	2.44	1.55	2.22	8th
2 – Regulatory Changes to Foster Innovation in the Energy Sector	1.07	4.21	0.63	4.43	1st
3 – Improvement of Research & Development and Demonstration Projects	1.23	4.12	1.15	4.07	2nd
4 – Incentive Policies for Promoting Demand-Side Management, Distributed Generation and Storage	1.42	3.47	1.04	3.75	6th
5 – Establishing Quality Standards for the Telecommunications Industry	1.71	3.16	1.50	2.62	7th
6 – Regulation of New Business Models	1.27	3.82	0.88	4.04	3rd
7 – Development Plan for Smart Cities	1.28	3.62	1.15	3.86	4th
8 – National Development Policy for Smart Grid Industry	1.11	3.82	1.11	3.86	5th

Table 8
Question #8: Relative importance of the objectives.

Objectives	SD1	AM1	SD2	AM2	Ranking
Objective 1: benefit the environment and human health	1.29	3.74	1.14	3.54	7th
Objective 2: enhance flexibility and capabilities of the system technological infrastructure	0.89	4.03	0.71	4.14	3rd
Objective 3: ensure security of supply	0.96	4.2	0.90	4.18	2nd
Objective 4: ensure openness, fairness, transparency and efficiency of markets	0.88	3.77	0.74	4.04	5th
Objective 5: provide financial benefit to the agents involved	0.97	3.37	0.80	3.75	6th
Objective 6: provide economic and social benefit to the country	0.85	4.43	0.83	4.61	1st
Objective 7: ensure feasibility and promote the adoption of technological innovations	0.76	3.89	0.80	4.14	4th

results of the first and the second rounds of the Delphi method. The standard deviation (SD1 e SD2) and the arithmetic mean (AM1 and AM2) of each round are presented, as well as a ranking of the proposed policies considering the objective addressed in the question (for question 8, the corresponding table presents the ranking of the objectives). The rankings are based on the arithmetic mean (average score) obtained by the answers of the experts after the second round of the questionnaire (Tables 1–8).

6. Discussion

Starting from a more specific analysis of the results obtained by the application of the Delphi questionnaire, it is possible to identify some policies that stand out in relation to the others. For example, the "Incentive Policies for Promoting Demand-Side Management, Distributed Generation and Storage" policy obtained the best rank in four of the objectives, as well as the second rank in another objective. It is noteworthy, however, that this policy had its worst rank, in the sixth place, in the objective "Ensure Feasibility and Promote the Adoption of Technological Innovations". We believe this result was not a negative appreciation, but rather an above-average assessment of the other policies regarding this objective. The respondent's answers did not reveal major differences between the responses of the different stakeholders. Another policy that stands out for its good performance under all objectives is the "Regulatory Changes to Foster Innovation in the Energy Sector" policy. This policy was never below the fourth rank. This result is very significant in respect to supporting its implementation.

Similarly, it is possible to identify the policies that presented the worst performance. The results are quite clear in pointing out that the "Mandatory Rollout of Smart Meters" and "Establishing Quality Standards for the Telecommunications Industry" policies have obtained the worst ratings. This result is particularly relevant, and somewhat surprising, given that rollout of smart meters is one of the most widespread policies internationally (although some case studies have reported the rollout of smart meters as failed public policies, namely in UK and Australia). One possible interpretation of this result is the perception that the rollout of smart meters is only pertinent in a context where dynamic electricity tariff schemes are established. In this sense, the adoption of regulatory changes becomes a priority in relation to the rollout of smart meters. The classification of "Establishing Quality

Standards for the Telecommunications Industry" policy is also relevant, especially considering the precariousness of the Brazilian telecommunications network. This means that the electricity distribution companies have to build their own telecommunication networks, entailing a significant increase in costs for their smart grid projects.

The policy of "Establishing Quality Standards for the Telecommunications Industry" obtained the lowest degree of consensus. For all objectives, this policy had the highest or second highest standard deviation after the second round of the Delphi questionnaire. The reason for such a divergence can be found by sorting the data by group of stakeholders. There was a remarkable divergence between the areas of knowledge group of respondents and electricity companies. Under all objectives, the knowledge group presented average scores significantly higher than those found for the electricity companies group. Thus, there may lack of support from the electricity companies regarding the adoption of this policy.

There is, however, a set of policies that is not clearly classified as positive or negative: “Improvement of Research & Development and Demonstration Projects”, “Regulation of New Business Models”, “Development Plan for Smart Cities” and “National Development Policy for Smart Grid Industry”. Nevertheless, it is possible to highlight some interesting results regarding these policies. Firstly, the policies of "Development Plan for Smart Cities" and "National Development Policy for Smart Grid Industry" did not rank below the fifth position, i.e., they were not poorly evaluated under any objective. This shows a good acceptance for their adoption, that is, there is no obvious barrier to their implementations.

The policy of "Regulation of New Business Models", in turn, presented good rankings in most of the objectives. However, two observations are in order. First, with a fairly high degree of consensus, this policy was ranked as the most recommended under the objective of "Provide Financial Benefit to the Agents Involved". This result seems quite consistent, given that the entry of new business models will most likely bring benefits to the agents involved. Second, the objective that gave the worst rating for this policy was to "Ensure Security of Supply", in sixth place. Thus, it is expected that the regulation of new business models does not help in a decisive way to ensure the security of supply.

Among the four policies that did not present markedly positive or negative position, it is possible to point out the policy of "Improvement of Research and Development and Demonstration Projects" as the least recommended, since it was ranked in sixth place in five of the seven objectives. However, this policy presented a very satisfactory result for the objective "Ensure Feasibility and Promote the Adoption of Technological Innovations", for which it was placed in second position. This result can be explained mainly by the evaluation of the knowledge and electricity companies groups that presented average scores significantly higher than the government group. It is therefore inferred that, for knowledge and electricity company groups, R&D projects assume greater importance than for the government group.

Considering the information in a disaggregated way, that is, from the perspective of each group of stakeholders, it is possible to identify how each group evaluated the policies. The results of the Delphi questionnaire revealed that the knowledge group was the one presenting the highest evaluations for all policies, except for "Incentive Policies for Promoting Demand-Side Management, Distributed Generation and Storage" in which this policy obtained the second highest position. The government group was the one which most supported this policy. For the other policies, the government group had the second highest average, except for the "Smart Meters Roll Out Mandatory" policy, which obtained the lowest average score. It may be inferred from these results that, in general, the knowledge group is the one that most supports the policies, followed by the government group. Thus, the effort to implement the policies under assessment should take into account the willingness of electricity companies for their adoption. This group assigned the lowest average score for five of the seven policies assessed.

More broadly, some interesting results can be presented. First, it is important to note that no policy presented a negative average score under any evaluation criteria. This shows that all policies are classified as beneficial to the system and, in some way, have merit to be implemented. It should be noted, however, that there are policies consistently with more support than others, as already discussed. Although there are no policies that are classified as not recommended, when considering the averages after the second round of Delphi, it stands out that some policies had negative individual assessments by some experts. These are the "Mandatory Rollout of Smart Meters" and "Establishing Quality Standards for the Telecommunications Industry" policies, which might face some resistance to their enforcement. Second, it is worth highlighting that the best classified policies, "Regulatory Changes to Foster Innovation in the Energy Sector" and "Ensure Feasibility and Promote the Adoption of Technological Innovations", obtained very high degrees of consensus for all evaluation criteria.

Question #8 asked the experts their views on the relative importance of each objective addressed in previous questions. In this respect, the result of the Delphi questionnaire indicated clearly that the objective with the highest importance was "Provide Economic and Social Benefit to the Country". The policy with the best classification under this objective was "Incentive Policies for Promoting Demand-Side Management, Distributed Generation and Storage", while the worst was "Mandatory Rollout of Smart Meters". The objective with the second highest degree of importance was "Ensure Security of Supply". However, the difference in average rating that separates the second rank from the fifth rank is small (0.14). Meanwhile, the objectives with the worst and the second worst rankings were “Benefit the Environment and Human Health” and “Provide Financial Benefit to the Agents Involved”. The main implication of question # 8 is the possibility of using such information as parameters for more sophisticated multi-criteria decision analysis methods.

7. Conclusions and policy implications

The economic characteristics of the electricity sector require the adoption of incentive policies to foster technological innovations in the realm of the evolution of electricity networks to smart grids. The definition of the policies, as well as a comprehensive assessment framework, should involve the perspectives of relevant stakeholders. This has been carried out in the R&D project “Evaluation of policies and incentive actions for technological innovations in the electricity sector: analysis of the international experience and proposals for Brazil”, in which a Delphi study has been conducted to assess the effectiveness of representative policies to succeed in achieving the objectives associated with investments in smart grids.

A first and important conclusion of the assessment of public policies under analysis is that all obtained a positive average score in all questions, i.e., all policies were assessed as being positive for all objectives. This means that the experts classified all policies as good policies to be adopted, differing only in the priority that each policy should be assigned to. This is not surprising because all these policies were chosen based on literature reviews and the experience of several countries that have been implementing such policies. Although there are no policies classified as not recommended, when considering the average scores after the second round of Delphi, it can be noted that some policies had negative individual assessments by some experts. The main implication of this finding is that these assessments can act as barriers to be overcome for the adoption of these policies.

The main value of the approach followed in this work is indeed to identify where consensus or disagreement lies, among a diversity of stakeholders, and to identify which policies are the most promising ones. This is an important output considering that the detailed design of a policy and a detailed assessment of its costs and benefits is a costly and time-consuming endeavor. Therefore, the resources and the attention of policy makers can be directed to policies that they know have good prospects of success, as the ones emerging from this study.

It is important to emphasize that policies were assessed considering distinct objectives and each question addressed these objectives separately. Attention is drawn to the fact that for every objective a distinct final classification was obtained. Thus, in order to conduct a global assessment of the public policies, i.e. evaluating the policies on the multiple objectives simultaneously, the adoption of other methodologies is required, such as multi-criteria decision analysis/aid (MCDA) methods [70,71]. These methods are able to consider the relative importance of objectives according to meaningful information elicited from decision makers, as well as other preference information parameters to derive recommendations according to the selection, ranking or sorting perspectives.

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Appendix A. – Survey questions

See Figs. 1–3

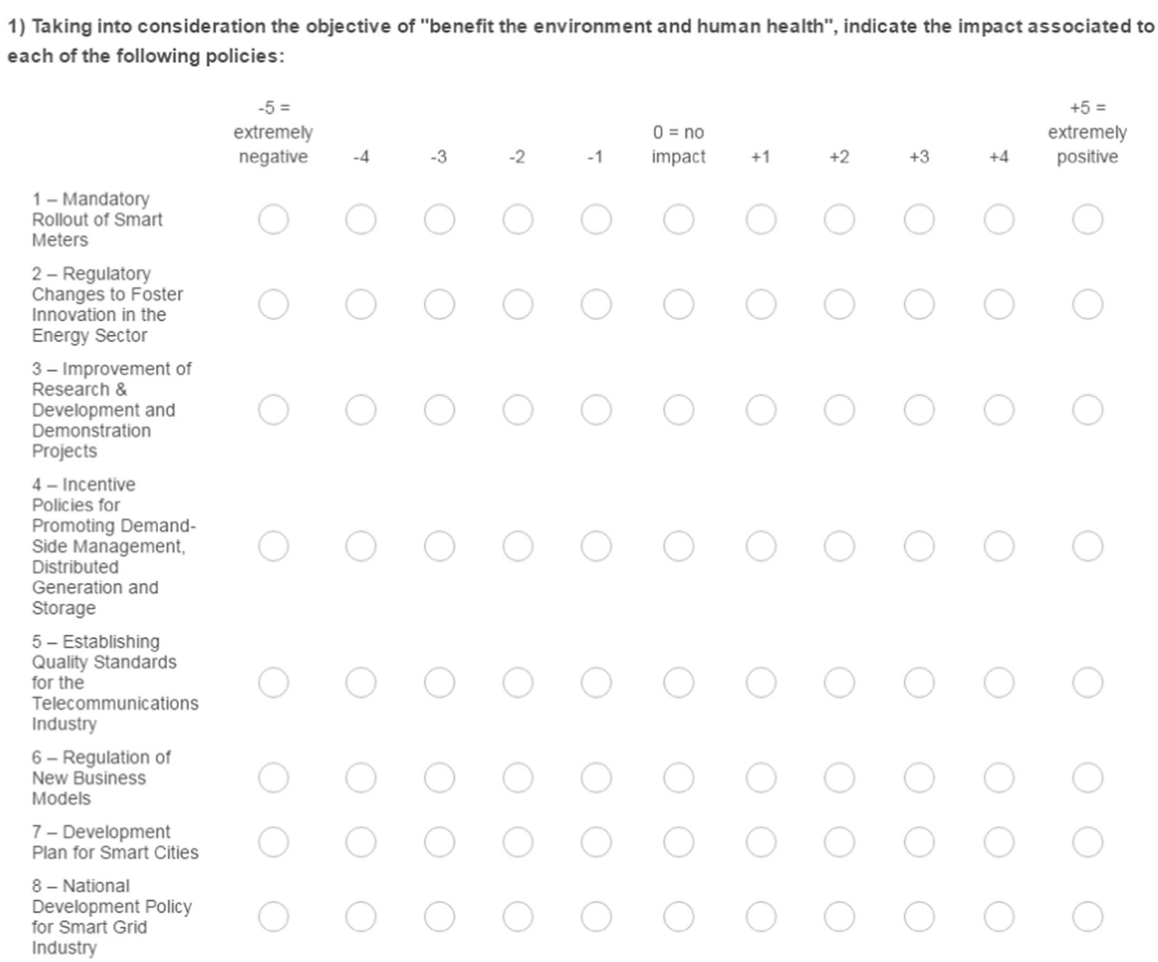
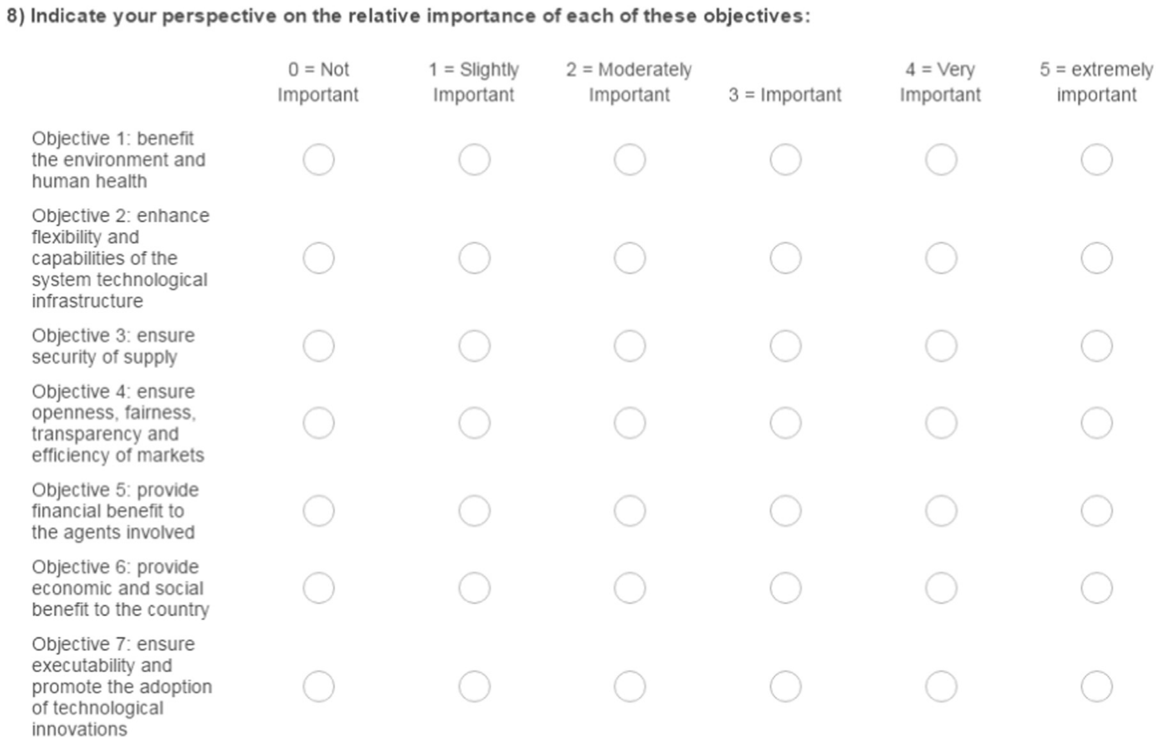


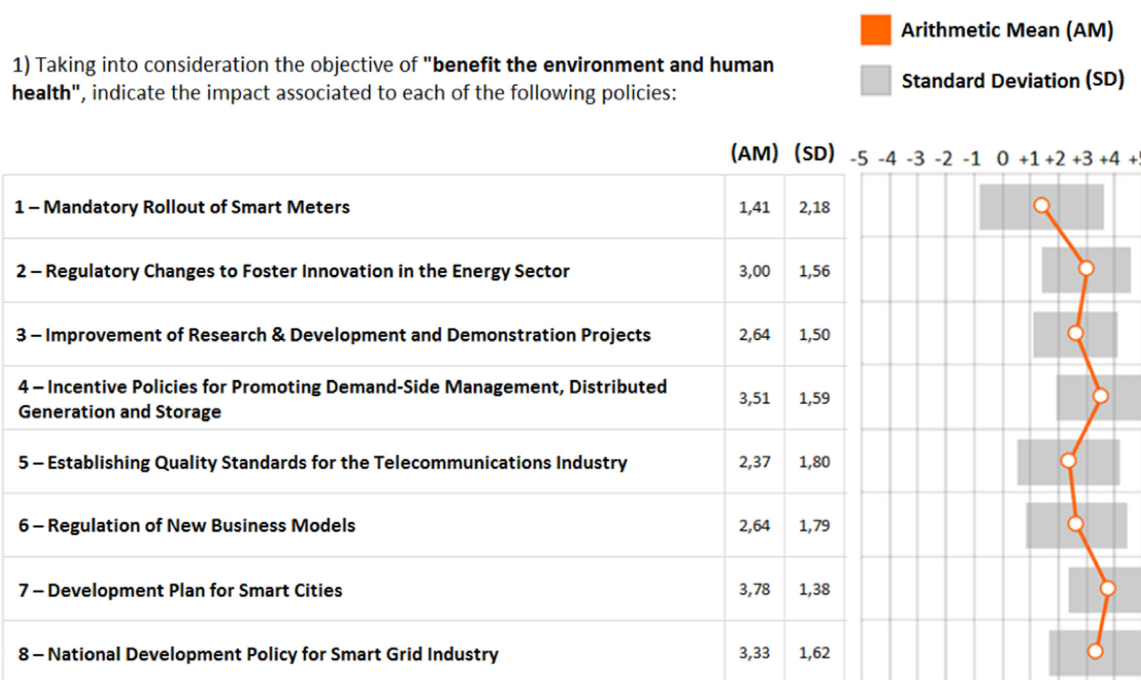
Fig. 1. Question #1 of the first Delphi questionnaire.



8) Indicate your perspective on the relative importance of each of these objectives:

	0 = Not Important	1 = Slightly Important	2 = Moderately Important	3 = Important	4 = Very Important	5 = extremely important
Objective 1: benefit the environment and human health	○	○	○	○	○	○
Objective 2: enhance flexibility and capabilities of the system technological infrastructure	○	○	○	○	○	○
Objective 3: ensure security of supply	○	○	○	○	○	○
Objective 4: ensure openness, fairness, transparency and efficiency of markets	○	○	○	○	○	○
Objective 5: provide financial benefit to the agents involved	○	○	○	○	○	○
Objective 6: provide economic and social benefit to the country	○	○	○	○	○	○
Objective 7: ensure executability and promote the adoption of technological innovations	○	○	○	○	○	○

Fig. 2. Question #8 of the first Delphi questionnaire.



	(AM)	(SD)
1 – Mandatory Rollout of Smart Meters	1,41	2,18
2 – Regulatory Changes to Foster Innovation in the Energy Sector	3,00	1,56
3 – Improvement of Research & Development and Demonstration Projects	2,64	1,50
4 – Incentive Policies for Promoting Demand-Side Management, Distributed Generation and Storage	3,51	1,59
5 – Establishing Quality Standards for the Telecommunications Industry	2,37	1,80
6 – Regulation of New Business Models	2,64	1,79
7 – Development Plan for Smart Cities	3,78	1,38
8 – National Development Policy for Smart Grid Industry	3,33	1,62

Fig. 3. Feedback provided to the experts in the second questionnaire.

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