Costs and Benefits of the Implementation of Smart Grids in the European Union

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Abstract— This paper discusses the costs and benefits of implementing smart grids in EU member states. Only six EU member states have achieved full coverage with smart meters. Smart grids contribute to increasing energy efficiency, balancing demand and supply for electricity and reducing harmful impacts on the environment. There are four regulatory incentives for Distribution System Operators cost efficiency and productivity. The treatment of costs in the functioning of energy distributors differs between countries. According to the capacities of Distribution System Operators for the application of smart grids, countries can be grouped into three clusters. EU member states are divided into two groups according to the net benefit from the application of smart meters. Although the capacities for integrating a smart grids into the energy system are the largest in Germany and the Czech Republic, in these two countries the cost benefit analysis of smart meters gives negative results..

Keywords - smart grid, smart meters, cost, benefit, European Union

I. INTRODUCTION

Due to the current conflict in Ukraine, the energy stability of the European Union is at risk. Despite the energy sector development strategies, the current situation has shown all the disadvantages of energy dependence on the Russian Federation. An effort made more urgent by the need to discover other sources of economic and industrial advantage outside of Russian gas would result in a 20% reduction in the EU's natural gas and oil demand this decade and a 50% reduction in coal demand [1].

The European Green deal can help the EU accomplish its revised 55% emissions reduction objective. In addition to the pre-pandemic baseline and the 40% objective, half of the deficit may be closed in the electricity sector, followed by transportation decarbonization. However, investments as part of the EU's green recovery can only support around half of this effort on a conditional basis. Additional investments and financial mechanisms are necessary to provide a route to 55% by 2030, particularly given the consequences of the newly announced REPowerEU initiative. Plans such as the REPowerEU, as well as other investment schemes that may follow in the near future, must be well prepared to prevent the danger of probable fossil fuel rebounds following COVID-19, despite the fact that the epidemic itself has been determined to have little influence on long-term emission trajectories [2].

Smart grids are particularly useful for integrating increasing amounts of variable renewable energy sources (RES), storage of energy, and electric car charging while retaining the system's efficiency and reliability. Smart grid provide data on supply and demand. Additionally, smart grids give users who generate their own energy the opportunity to react to pricing by returning any excess to the grid. With the help of smart grids, new market participants may supply customers with new kinds of services, allowing them to adapt their consumption and profit from the flexibility the grid has access to [3].

European Union provides a comprehensive framework for the integration of energy policies throughout its member states. Smart grids are intended to help to the EU's long-term goals, which include increasing energy efficiency and share of RES by 27% by 2030, and lowering greenhouse gas emissions. The European commission has placed a special priority on the large-scale roll-out of smart metering throughout all member countries, as envisaged by Electricity Directive from 2009, in order to include consumers in their active participation in the energy supply market [4]. Through a variety of features, smart meters should enable customers to take benefits from the gradual digitalization of the energy industry. Additionally, consumers should have quick access to contracts with dynamic power prices and data on their energy use. Nearly 77% of European users are anticipated to have a smart meter for electrical energy by 2024, and 44% will have a smart meter for gas [5].

II. THEORETICAL BACKGROUND

The first project, which installed 45 million smart meters throughout the EU's 12 member states, launched European smart grid initiatives in 2001. The implementation of smart meters decreased energy use by up to 10%. The development of smart grid technology and policies should go hand in hand. Energy security, supply dependability, economic opportunities, and impact mitigation are all advantages of smart grids. Future grid success depends on political and regulatory support, attention, and the restructuring of energy production, market, and consumption. Significant expenditures will be needed to make the transition to a smarter electrical grid [6].

Study [7] demonstrate that DSOs invest significantly more on average in markets with low market concentration ratios than in those with high ratios. The average investment in SG in the first group of countries was €206 per million of GDP, compared to €104 per million of GDP in the second group. Regulation with incentives may encourage the development of the smart grid and related investments. Investments averaged €130 per million of GDP in states with incentive-based regulation, compared to €78.6 per million of GDP in states with cost-based regulation. Similar to how an incentive-based scheme would be more successful than a hybrid model, a hybrid approach might also be beneficial in delivering investment incentives for smart grid [7].

Study by [8] shown that when incorporating RES, the adoption of a smart grid may considerably increase the dependability and stability of the energy system. The same study also discovered that using smart grid technologies can decrease the need for additional transmission and distribution equipment, thereby saving grid operators money [8].

The entire power consumption of communication networks and data centers, in particular, is equivalent to that of big countries. As a result, with rising power prices and looming carbon restrictions and taxes, the operational expenditures (OPEX) of communication networks and data centers are increasing. As a result, significant efforts have lately been made to improve the energy-efficiency of ICTs. Smart grid-driven strategies, in addition to traditional ways, have found their way to give OPEX savings. The smart grid has introduced new concepts including as dynamic pricing systems, distributed generation, demand management, and fine-tuned monitoring of faults and disturbances, which may be efficiently used to minimize ICT costs, consumption, and emissions [9], [10]. Faruqui et al [11] estimates the cost of installing smart meters in the EU and suggests that dynamic pricing enabled by smart meters can reduce peak demand and lower the need for expensive peaking power plants, resulting in operational savings.

According to a research [12], the integration of RES presents certain difficulties, including weather unpredictability, noise pollution, and high transportation costs. The utility may be able to minimize the peak power consumption during on-peak hours with the penetration of Plug-in Electric Vehicles (PEVs) and Energy Storage System, which has advantages for the environment and the economy. Integration of RES with PEVs has a great deal of potential to reduce CO2 emissions, resulting in more environmentally friendly electricity. The smart grid idea is present across the whole power system with the goal of delivering more dependable, affordable, and sustainable electrical networks. When RESs, battery storage systems, and PEVs are integrated, however, it necessitates new control strategies. Smart grids can help with environmental preservation, the promotion of green energy, and improving grid stability [12].

Given the current environment of growing power demand, smart meters are essential for the seamless functioning and management of the future smart grid. With such a capability, load forecasting should be easier and more precise in order to deal with the future energy market. Furthermore, authentic datasets created by smart meters will be able to be sent directly to a server for more accurate analysis. The obtained data can be used for parametric and non-parametric predictive models. Non-parametric approaches employ non-linear data and are based on AI, whereas parametric methods use linear data. It is also noticed that, in addition to historical data from smart meters, several algorithms incorporate meteorological data and time period as inputs to their models. Key metrics of energy performance are utilized for each model to determine system correctness [13], [14]. On a sample of 64 European DSOs, the study [15] shows that traditional financial indicators are not good enough to show the profitability of investing in new digital technologies in the energy sector, such as smart grids and smart meters.

Study by [16] emphasizes the importance of conducting a comprehensive cost-benefit analysis of smart grid projects due to their large investment and delayed benefits. In study by [17] researchers models a smart municipal energy grid and finds that it can decrease total yearly community energy costs and reduce CO2 emissions. According to [18] researchers builds a model to evaluate the costs and benefits of each system in the smart distribution network and finds that it is more secure, efficient, economic, and environmentally friendly compared to traditional distribution networks. Overall, the model suggest that while there are costs associated with implementing smart grids in the EU, the benefits include operational savings, decreased energy costs, and reduced CO2 emissions [18].

The potential for the application of smart grids also exists in Serbia. The Republic of Serbia has a large energy potential for the use of renewable energy sources. Because of the incentive system in the form of feed-in tariffs, there is a growth in investments in the energy sector [19]. In study by [20] developed a BI model for the needs of the main electricity distributor in Serbia. The model is adapted to developing energy markets and includes three main components: balance responsibility, balance mechanism and allocation of cross-border capacities. According to the study [21] conducted in Serbia, consumers' views toward environmental preservation and green energy drive them to engage in new smart grid services. Furthermore, attitudes regarding these incentives fluctuate among age groups. Participants in the age ranges 31-50 may be more interested since they are more aware of environmental challenges [21].

III. IMPLEMENTATION OF SMART GRIDS

A. Research questions

Based on the review of the literature and available data from the publications of international institutions, several research questions were formulated that were attempted to be answered in this paper:

- Is it possible to measure the effects of the implementation of smart grids with financial indicators?
- What are DSO's capacities for the integration of smart grids and smart meters?
- What are the costs and benefits of implementing smart meters in EU countries?
- Is it possible to group EU member states according to the level of smart grid implementation?

B. Cost efficiency and productivity

The calculation of the WACC (Weighted Average Cost of Capital) is a critical component of the used regulatory procedures. Sectoral regulators determine the WACC in regulated contexts, such as the energy distribution industry, and the DSOs are reimbursed for the opportunity costs of capital through the WACC. Both the cost of debt and the cost of equity are taken into account by the WACC.

Consumers will pay a high price if the WACC is set above the future opportunity costs of capital, while network operators may not be able to cover expenditures that would improve the quality of network services if the WACC is set below those costs. Recent increases in EU inflation have brought it to levels not seen in more than 20 years. If the inflation anticipation is different from the actual inflation, DSOs who borrow in nominal terms are at danger. The more unclear real inflation outcomes are, the greater the danger. With rising loan rates brought on by higher capital costs due to growing inflation, DSOs may find it more difficult to invest in network assets and grid modernisation [22].

To group European countries by regulatory schemes, use various criteria. Group European countries by regulatory schemes using various criteria. In study [23] discusses about regulatory incentives for DSOs' cost efficiency and productivity. This study categorizes models into four types: price-cap, revenue-cap, cost-plus, and hybrid. In the study sample of 22 member states of the EU, 59% use revenue-cap systems, 14% use price-cap schemes, 14% use hybrid schemes, and 14% use cost-plus schemes. The Dutch price-cap regulatory scheme is an often cited example. Price-cap regulation has been used in the Netherlands since the first price control in 2002. The revenues that DSOs are permitted to generate during a regulation period are fixed and established using a mathematical formula under this framework. This strategy incentivizes network operators to reduce expenses in order to maintain or enhance profitability. Similarly, the main premise of price control in Slovakia employs a price-cap as a technique, which assures profit only under truly efficient company operations and encourages network providers to lower their own losses. Quite unexpectedly, in Slovakia, the price cap is established independently for each voltage level [24].

Currently, only Belgium, Croatia, and Estonia use cost-based regulatory frameworks. Typically, significant quality of service or other types of incentives are integrated with cost-plus regulatory frameworks in countries where they are used. As an illustration, the regulator in Belgium uses a sophisticated cost-plus model that combines a profit-sharing (PS) and a quality-of-service (QoS) mechanism. As part of the PS cost-reduction mechanism, the operator is rewarded for keeping real expenditure under budget by retrieving 50% of the difference (up to a cap of 10% of the budget). A few European regulatory authorities have created and put into place hybrid models that integrate rate-of-return, price-cap, and/or revenue-cap regulatory regimes. Italy, Portugal, and Hungary are among these countries that employ hybrid regulatory frameworks [24], [25].

Many hybrid models address capital costs (CAPEX) using a cost based approach and OPEX using an incentive based approach. The hybrid system in Portugal uses a price-cap model for the treatment of OPEX and a rate-of-return model for the handling of CAPEX for activities at the medium voltage network level. Another example is the Italian regulatory framework, where the regulator has encouraged DSOs to reduce OPEX while paying out the invested capital at a predetermined rate over four years. The Hungarian incentive regulation resembles a price-cap system in theory, but in reality, it mixes elements of quality regulation, revenue caps, and price caps [25].

The regulatory authorities in most EU members have a non-TOTEX approach, handling CAPEX and OPEX differently. Almost 80% of countries and DSOs use the non-TOTEX approach, while the other approach is present only in Croatia, Denmark, Portugal, Germany, and the Netherlands.

C. Capacities of Distribution System Operators

In order to be able to see the possibilities for the implementation of smart grids in the existing energy sectors of the EU member states, it is necessary to see the capacities of DSOs. Within the European Union, there are over 2.5 thousand DSOs, of which each of the 182 DSOs meets the needs of over 100 thousand customers. Fig. 1 shows the total number of DSOs by country and the number of DSOs that meet the needs of over 100 thousand users for each member country. The most DSOs are present in Germany (882), which also has the largest number of DSOs serving over 100,000 customers (80 DSOs). It is followed by: Spain with 354 DSOs, the Czech Republic (290), Poland (180) and Sweden (170).

Based on the number of DSOs serving more than 100 thousand customers, countries can be grouped into several clusters: countries with 8-12 DSOs, countries with 2-7 DSOs and countries with one DSO. Germany is not included in the clusters because the number of DSOs serving over 100,000 users is much higher compared to all member countries, and neither is Malta due to the number of consumers. The first cluster of countries consists of: Austria, Belgium, Denmark, Finland, Italy, and Romania. The second cluster of countries consists of Bulgaria, Czech Republic, France, Hungary, Netherlands, Poland, Slovakia, Spain, and Sweden. The third cluster of countries consists of Estonia, Croatia, Cyprus, Greece, Ireland, Latvia, Lithuania, Luxembourg, Portugal, and Slovenia [26].

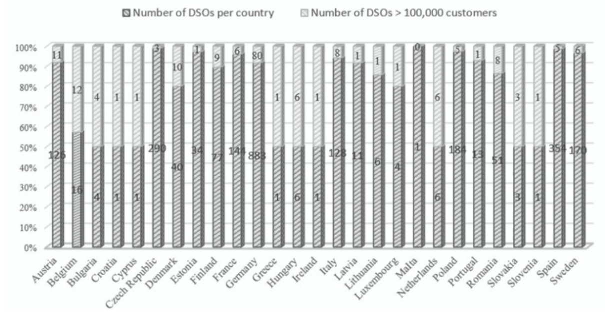

Fig. 1. DSOs in the EU member states in 2020, adapted from [26]

D. Smart meters

The coverage rate is calculated as the proportion of end users who have smart meters compared to all other end users in the DSO region covered. These statistics allow to identify five distinct degrees of coverage: There are five different roll-out stages: 1) Completed roll-out; 2) Nearing completion, 3) In process, 4) Early stage (pilot project), and 5) No roll-out.

On the one hand, DSOs who have finished a roll-out program and achieved an average of 97% coverage are those that have done so with full coverage throughout their service region. These DSOs have been included in group 1. On the other side, fourth group is given to DSOs that have installed smart meters for less than 20% of their consumers, attaining an average customer coverage of 10%.

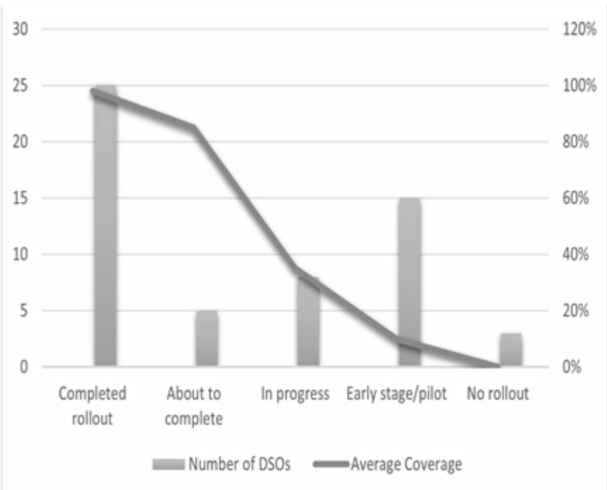

Fig. 2. The coverage rate of DSOs by smart meters in 2022, adapted from [24]

By the end of 2022, a few Member States will have achieved the Directive's criteria (80% coverage by 2020), while others will have fallen short or given up entirely. DSOs were grouped together in first group because, as was predicted, the degree of smart meter penetration is near to 100% in Member States where a nationwide roll-out has been completed. Italy, Sweden, Finland, Spain, Denmark, and Estonia are a few of the top EU nations for the implementation of smart meters [24].

Table 1 shows data for 22 member countries for which data were available. For Finland, France and Malta, there is no data on the benefits of smart meters, so the net benefit cannot be measured. In terms of costs, smart meters are the most expensive in the Czech Republic, followed by Austria, Germany and Ireland. The lowest costs of smart meters are in Portugal, Romania, Italy, and Malta.

If the net benefit is considered as the difference between benefits and costs per unit for smart meters, EU member states can be divided into two groups. The countries that realize a net benefit are: Greece, Estonia, Portugal, Italy, Ireland, Austria, Netherlands, Sweden, Luxembourg, Poland, Denmark, and Slovak Republic. The largest net benefit per meter point was achieved by Greece and Estonia. The second group of countries consists of those countries that realize a net loss according to this criterion: Romania, Lithuania, Germany, Czech Republic, and Latvia. These results are not expected since the second group of countries includes countries that have low unit costs of smart meters [25].

In order to improve the level of coherence across European, national, and regional activities addressing smart grids, the Smart Grids European Technology Platform was founded in 2004. This platform's collaboration with other nations, particularly North America and Japan, played a crucial role in ensuring that the development of commercial goods and the global expansion of smart grids are complimentary. The British government has created a number of organizations and platforms to boost donations towards the construction of smart grids. The Energy Technologies Institute, a collaboration between the UK government and business sectors, is a good example. It permits the accelerated development of green technologies, such as energy storage, building energy management, and DSOs, with a flexible mix of public and private finance [27]. The countries of the Western Balkans have adapted the regulatory framework for energy to the directives of the European Union. In these countries, especially due to their potential in the field of RES and geographical proximity to the EU, there is a possibility for the application of smart grids and inclusion in already existing EU transnational projects of smart grids. However, due to insufficient investment in the energy sectors of the countries of the Western Balkans, the implementation of smart grids significantly lags behind the countries of the European Union [28].

Table I. Cost and benefit per metering point

Country	Cost per metering point in euros	Benefit per metering point in euros	Net benefit in euros
Austria	590	654	64
Czech Republic	766	499	-267
Denmark	225	233	8
Estonia	155	269	114
Finland	210	n/a	n/a
France	135	n/a	n/a
Germany	546	493	-53
Greece	309	436	127
Ireland	473	551	78
Italy	94	176	82
Latvia	302	18	-284
Lithuania	123	82	-41
Luxembourg	142	162	20
Malta	77	n/a	n/a
Netherlands	220	270	50
Poland	167	177	10
Portugal	99	202	103
Romania	99	77	-22
Slovak Republic	114	118	4
Sweden	288	323	35

IV. CONCLUSION

The integration of the smart grid into the existing energy system leads to benefits that can be qualitatively and quantitatively expressed. Demand response is one way smart grids enhance energy efficiency. Consumers are encouraged to limit their energy use during peak hours, when power demand is highest. Smart grids can help these initiatives by giving users with real-time data on their energy consumption and allowing them to alter their consumption accordingly. This can assist decrease the need for extra power plants to be brought up during peak hours, which can be costly and polluting, as well as gather enough information to provide customised demand response services. The main advantage is in increasing the stability and efficiency of the energy sector. This is especially pronounced when it comes to RES, primarily due to seasonal variations in the production of energy from different renewable sources. Smart grid can to enhance economic growth, create new green jobs, and improve environmental protection.

However, consumer awareness and education about the smart grid is needed to improve consumer acceptance and protection. Data protection is one of the possible problems in the operation of smart grids.

Implementing smart grids in the EU can bring benefits, but requires careful planning and analysis to ensure economic viability and optimize the energy system. In terms of monitoring the costs of operating DSOs, there is no uniform methodology in all member countries. Due to the different models for evaluating the efficiency and productivity of the energy sector, it is difficult to make comparisons between countries. Although DSOs capacities are the largest in Germany and the Czech Republic, in these two countries the cost benefit analysis of smart meters gives negative results. Future directions of research can be oriented towards the construction of indicators that will enable a more precise comparison between member countries in which smart grids are implemented.

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