frontiers | Frontiers in Energy Research

OPINION
published: 22 July 2022
doi: 10.3389/fenrg.2022.944798

Smart Grid: Leading International Experience of Marketing and its Contribution to Sustainable and Environmental Development of Energy Economy

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Specialty section:
This article was submitted to Sustainable Energy Systems and Policies,
a section of the journal Frontiers in Energy Research

Received: 15 May 2022
Accepted: 24 June 2022
Published: 22 July 2022

Citation:
Mustafin TA, Kuprianova LM, Ladogina AY and Pyatkova ON (2022) Smart Grid: Leading International Experience of Marketing and its Contribution to Sustainable and Environmental Development of Energy Economy.
Front. Energy Res. 10:944798.
doi: 10.3389/fenrg.2022.944798

Keywords: smart grid, advanced international experience, sustainable and environmental development, energy economy, strategic perspective

INTRODUCTION

This article is devoted to the study of the contribution of Smart Grid to the sustainable and environmental development of energy. The central category in the article is Smart Grid, which refers to the "smart" technologies used for automation and enhanced environmental monitoring and control of energy production, distribution and consumption. Smart Grid includes, firstly, an extensive telecommunications infrastructure that provides high-precision and continuous measurement of energy efficiency and other energy characteristics. Secondly, the "smart" technologies used by energy companies themselves.

Initially, Smart Grid was created to increase the efficiency of the energy economy and optimize its flows to ensure the availability of energy resources for all economic entities. At the current stage, the advanced energy economies that were the first to create Smart Grid have fully implemented the initial tasks and achieved outstanding success, including energy conservation and mass electricity supply with full coverage of business structures and households. This raises two research questions.

RQ1: What are the future prospects for the development of Smart Grid? Numerous evidences of its benefits for the environment in the studies of Amir et al. (2022), Gajić et al. (2022), Sudhakar and Kumar (2022), Tabar et al. (2022) allow us to hypothesize that Smart Grid can contribute to the development of "clean" (renewable) energy. RQ2: How to realize these prospects and extend the successful experience of Smart Grid to other countries? To answer this question, it is necessary to systematize and analyze the factors of Smart Grid development, as well as to form a scientific basis for managing these factors. The purpose of the article is to study the contribution of Smart Grid to the sustainable and ecological development of the energy economy, as well as the prospects for increasing this contribution with the help of management mechanisms.

The contribution of the article to the literature consists in the formation of a new scientific take on Smart Grid, revealing its contribution to the sustainable and environmentally friendly development of the energy economy. Thus, the article establishes a methodological framework for the consistent achievement of not only energy efficiency, sufficiency and continuity of energy through the development of Smart Grid, but also the sustainability and environmental friendliness of the energy economy. This extends the current concept of Smart Grid and allows using it more flexibly in practical terms of environmental economics and management.

Smart Grid as a Vector of Energy Economy Development

The topic of Smart Grid is widely discussed in existing scientific publications, which indicates its high relevance. The works of Ali A. O. et al. (2022), Dehalwar et al. (2022), Hua et al. (2022), Ibrahim et al. (2022), Kamruzzaman and Alruwaili (2022), Omidvar Tehrani et al. (2022) note numerous advantages of Smart Grid, among which the optimization of production and distribution processes in the energy economy, reduction of losses and accidents in the production, storage and distribution of electricity.

Thus, first of all, Smart Grid has economic and social priorities. Some environmental aspects of Smart Grid are revealed in the available works of Ali S. et al. (2022), Kamruzzaman and Alruwaili (2022), Lamnatou et al. (2022), Popkova et al. (2021), Popkova and Sergei (2021), but in general, the ecological profile of Smart Grid has not been formed, which gives a partial picture of it from the standpoint of sustainable development.

The publications of Albogamy et al. (2022), Almutairi et al. (2022), Liu et al. (2022), Saxena et al. (2022), Zaidan et al. (2022) suggest the functioning and development of Smart Grid based on corporate governance with a secondary role of the state. Smart Grid is interpreted as a high-tech innovation of energy companies. The problem is that Smart Grid has largely revealed its potential as a vector for the development of the energy economy in the most progressive countries that were the first to create "smart" power supply networks. For example, in China, as one of the developing countries leading in the global SmartGrid SP Group development ranking (2022), noticeable progress has been made in increasing the share of the population with access to electricity from 96.907% in 2000 to 99.7% in 2010 and to 100% in 2013 (UNDP, 2022).

In India, progress is even more significant: the share of population with access to electricity increased from 59.125% in 2000 to 76.3% in 2010 and to 95.236% in 2018 (UNDP, 2022), and although data for later periods are still being calculated, we can expect that this share will tend to 100%. The future prospects of Smart Grid are uncertain, which is a gap in the literature. The ambiguity of the strategic vision of the future of Smart Grid hinders its development. To fill the gap formulated in this article, a factor analysis of the development of Smart Grid is carried out, and its contribution to the sustainability and environmental friendliness of the energy economy is determined based on the best international experience.

Smart Grid in the Energy Economy: Modeling and Policy Implications

Verification of the proposed hypothesis is carried out in this article using econometric modeling of Smart Grid as part of the energy economy. To study and highlight international best practices, the countries with the highest results in the field of Smart Grid (sg) development, whose companies/markets are leading in the SP Group (2022) rating for 2021, are included in the sample of countries for research. The justification for choosing Smart Grid Index as the resulting indicator is that this index way reveals the level of Smart Grid development in the most direct (straightforward), full and all-round (comprehensive) way.

The regression analysis method is used for obtaining the most accurate and reliable data, as this method makes it possible to perform both the stochastic factor analysis (to determine relationships between indicators) and the prospective factor analysis (use determined relationships as the basis for examining/predicting changes in factor and resulting variables over the longer term).

The advantage of the chosen method compared to the alternative method of deterministic factor analysis which is characterized by the functional relationship between factor variables and the resulting variable, is that it allows determining more flexible–probabilistic (correlation) and therefore the most reliable relationships of indicators. The benefit of regression analysis compared to its alternative in the form of dynamic factor analysis is the reduced risk of errors due to differences in approaches to calculating indicators, resulting in the data inconsistency.

To obtain the most accurate and reliable data, regression curves are constructed showing the consequences, firstly, the advantages of Smart Grid for the sustainable and ecological development of the energy economy through the prism of SDG 7 indicators: Population with access to clean fuels and technology for cooking (E1), CO_2 emissions from fuel combustion for electricity and heating per total electricity output (E2) and Share of renewable energy in total primary energy supply (E3) based on the materials of UNDP (2022). The justification for choosing these indicators is that it is the implementation of SDG7 that is the most important evidence of the sustainable and environmentally friendly development of the energy economy, while the UNDP is a reputable organization and a generally recognized provider of reliable statistics.

Secondly, the impact of the Smart Grid development factors allocated by the IMD World Competitiveness Center (2022): corporate governance factors–economic performance (f_1), business efficiency (f_2)—and government governance factors–government efficiency (f_3), infrastructure (f_4). The justification for choosing these indicators is that the IMD World Competitiveness Center is one of the most reputable providers of statistics on smart technologies that are fundamental for Smart Grid. The choice of these particular indicators is attributable to the fact that they allow taking into account both the corporate governance factors and the Smart Grid governance factors provided that these factors are comparable (the same units of measurement and the general methods for calculating their statistical values, since they are derived from the same report).

Based on the results of the analysis, Smart Grid governance factors that make the greatest contribution to the sustainable and environmental development of the energy economy are selected and qualitatively rethought, and energy policy implications are proposed. The statistical basis of the study is formed in **Table 1**.

Based on statistics from **Table 1**, the following econometric model (a system of linear regression equations) is obtained, which mathematically characterizes the Smart Grid as part of the energy economy:

$E_1 = -100{,}22 + 2{,}15sg;$

$E_2 = 3{,}55\text{-}0{,}03sg;$

$E_3 = -37{,}78 + 0{,}55sg;$

$sg = 92{,}02 + 0{,}12f_1\text{-}0{,}10f_2+0{,}03f_3\text{-}0{,}26\ f_4.$

The resulting model suggests that with an increase in the level of development of Smart Grid by 1 point, the share of the population with access to environmentally friendly fuels and technologies for cooking increases by 2.15% (correlation: 64.47%), CO_2, emissions from burning fuel for electricity generation and heating for the entire

TABLE 1 | Smart grid in the energy economy 2021.

Country	Utility	Smart Grid index, Score 0-100	Economic Performance, Place	Government Efficiency, Place	Business Efficiency, Place	Infrastructure, Place	Population with Access to Clean Fuels and Technology for Cooking (%)	CO_2 Emissions from Fuel Combustion for Electricity and Heating per Total Electricity Output ($MtCO_2/TWh$)	Share of Renewable Energy in Total Primary Energy Supply (%)
France	Enedis	96.4	28	39	36	15	100	0.537	10.682
United States	ConEd	96.4	5	28	10	6	100	1.145	7.915
Austria	CitiPower	92.9	20	29	18	12	100	0.936	30.187
Great Britain	UKPN	94.6	26	19	19	13	100	1.104	12.493
UAE	DEWA	89.3	9	3	8	28	98.51	1.505	no data
Denmark	Radius	85.7	17	7	4	3	100	0.990	36.931
Netherlands	Stedin	85.7	2	12	4	7	100	1.245	7.177
Japan	TEPCO	82.1	12	41	48	22	100	1.123	6.248
China	State Grid Beijing	80.4	4	27	17	18	59.26	1.407	no data
India	Tata power-DDL	80.4	37	46	32	19	41.04	1.462	no data

Source: IMD, World Competitiveness Center (2022), SP, Group (2022), UNDP (2022).

production of electricity decrease by 0.03 $MtCO_2/TWh$ (correlation of 60.60%), the share of renewable energy sources in the total volume of primary energy supplies increases by 0.55% (correlation of 27.94%).

The contribution to the development of Smart Grid was demonstrated only by government governance factors (multiple correlation with all governance factors 36.15%). Thus, with the improvement of government efficiency to 1 place in the international rating, the level of Smart Grid development increases by 0.10 points. With the improvement of infrastructure to 1 place in the international ranking, the level of Smart Grid development increases by 0.26 points.

Based on the obtained econometric model, a strategic forecast of the development of Smart Grid in the leading countries (included in the sample) based on management optimization is compiled. The obtained forecast assumes maximizing the government efficiency (improvement from 25.10th place for the sample mean to 1st place: –96.02%) and infrastructure (improvement from 14.30th place for the sample mean to 1 place: –93.01%). Thanks to this, the level of development of Smart Grid will increase by 6.56% (from 88.39 points to 94.19 points), which will contribute to:

– The share of the population with access to environmentally friendly fuels and technologies for cooking increased by 13.87% (from 89.88 to 100%);
– Reduction of CO_2 emissions from fuel combustion for electricity and heating per total electricity output by 13.80% (from 1.15 $MtCO_2/TWh$ to 0.99 $MtCO_2/TWh$);
– The share of renewable energy in total primary energy supply increased by 28.75% (from 11.16 to 14.37%).

The presented prospect for further development of Smart Grid is stochastic (probabilistic), since it is based on data on a sample of countries (rather than a single specific country) and projected (rather than actual, observed) indicator values. With the development of Smart Grid and the accumulation of statistical information, experimental evidence of the identified prospect would be expedient, which shall be understood to mean substituting the actual data into the formulated regression models for their refinement, as well as for the correction of forecast. The data for each regression model will be derived from subsequent official statistics (for 2022, 2023 and beyond) from the IMD World Competitiveness Center, SP Group, and UNDP.

These recommendations determined the algorithm for the sustainable and environmentally friendly development of the energy economy based on Smart Grid. At the first stage of the algorithm, government efficiency and infrastructure are maximized. At the second stage, the development of Smart Grid is achieved. At the third stage, the benefits for the sustainable and environmentally friendly development of the energy economy are derived through an increase in population with access to clean fuels and technology for cooking, a decrease in CO_2 emissions from fuel combustion for electricity and heating per total electricity output, and an increase in the share of renewable energy in total primary energy supply.

Other applications of the proposed algorithm include the decarbonization of the economy, the transition to renewable energy and the circular economy, and the development of responsible communities and sustainable territories. For real-time applications, consideration must be given to the performance of the technique–power-generation facilities used in Smart Grid. In addition, it would be expedient to rely upon state-of-the art solutions in the field of engineering and technical algorithms (Dhiman and Kumar, 2017; Dhiman and Kumar, 2018; Dehghani et al., 2019; Dhiman and Kaur, 2019; Dhiman and Kumar, 2019; Dehghani et al., 2020a; Dehghani et al., 2020b; Kaur et al., 2020; Dhiman et al., 2021a; Dhiman et al., 2021b; Chatterjee, 2021; Dhiman, 2021; Kumar and Dhiman, 2021; Vaishnav et al., 2021; Gupta et al., 2022; Sharma et al., 2022; Shukla et al., 2022), since this will allow for the most efficient government and corporate governance.

DISCUSSION

The contribution of the article to the literature consists in revealing the prospects for further development of Smart Grid and clarifying its organizational and managerial model. Unlike Ali A. O. et al. (2022), Dehalwar et al. (2022), Hua et al. (2022), Ibrahim et al. (2022), Kamruzzaman and Alruwaili (2022), Omidvar Tehrani et al. (2022), it was proved that the advantages of Smart Grid are not only support for mass accessibility, efficiency and security of the energy economy, but also an increase in its environmental friendliness (by an average of 14% compared to the level of 2021).

In contrast to Albogamy et al. (2022), Almutairi et al. (2022), Liu et al. (2022), Saxena et al. (2022), Zaidan et al. (2022), it was found that Smart Grid mainly depends on government governance, which includes both infrastructure support, and regulation of the energy economy. The role of corporate governance is secondary. This gives a new perspective on Smart Grid, transferring it from the category of high–tech innovations of energy companies (at the micro level–individual enterprises) to the state program for the development of the energy economy as a whole (at the meso-regional and macronational levels).

This allows us to offer a promising strategic vision of the future of Smart Grid, associated with the systematic modernization of the territorial economy and the integration of "smart" power supply networks into urban planning. In the authors' vision of Smart Grid, it is transformed from separate (isolated, disparate and small-scale) sections of high-tech power supply networks into a new format of electricity supply organization and a new technological structure of the energy economy.

Smart Grid's environmental priorities include: increasing access to environmentally friendly fuels and technologies for cooking, reducing CO_2 emissions from fuel combustion for electricity and heating per total electricity output, as well as increasing the share of share of renewable energy in total primary energy supply.

CONCLUSION

The result of the conducted research is the proof of the hypothesis put forward by the authors. Based on the best international experience, the article demonstrates that Smart Grid can contribute to the development of "clean" (renewable) energy. This new authors' vision is fundamentally different from some of the environmental benefits of Smart Grid noted in the literature, bringing it to the level of a vector of sustainable and environmentally friendly development of the energy economy.

The resulting factor models revealed the causal relationships of Smart Grid development, while the proposed recommendations determined the algorithm for sustainable and environmentally friendly development of the energy economy based on Smart Grid. At the first stage of the algorithm, government efficiency and infrastructure are maximized. At the second stage, the development of Smart Grid is achieved. At the third stage, the benefits for the sustainable and environmentally friendly development of the energy economy are derived through an increase in population with access to clean fuels and technology for cooking, a decrease in CO_2 emissions from fuel combustion for electricity and heating per total electricity output, and an increase in the share of renewable energy in total primary energy supply.

A stochastic forecast for the implementation of the proposed algorithm has been made. This forecast yielded the following benefits for the sustainable and environmentally friendly development of the energy economy: an increase in population with access to clean fuels and technology for cooking by 13.87% (from 89.88 to 100%); a decrease in CO_2 emissions from fuel combustion for electricity and heating per total electricity output by 13.80% (from 1.15 $MtCO_2$/TWh to 0.99 $MtCO_2$/TWh); an increase in the share of renewable energy in total primary energy supply by 28.75% (from 11.16 to 14.37%).

The scientific novelty of the article is to substantiate the serious contribution of Smart Grid to the sustainable and environmentally friendly development of the energy economy. Based on this contribution, a long-term strategic vision of the future of Smart Grid is proposed, supplemented by environmental priorities. The theoretical significance of the obtained results consists in the systematization and formation of the scientific basis for managing the factors of Smart Grid development. The practical significance of the authors' conclusions is related to the fact that they provided a scientific and methodological basis for improving the effectiveness of Smart Grid development management based not only on corporate, but also on government governance, which, as shown in the article, is even more significant.

The limitation and drawback of the proposed algorithm is its stochasticity–the flexibility of results and their dependence on the context, although the probability of the forecast is fairly high in general (more than 60%) and guarantees the benefits from the development of EnergyTech for the sustainable and environmentally friendly development of the energy economy. In future studies, in proportion to the accumulation of experimental (corporate–at the level of enterprises) and statistical data, it would be expedient to re-evaluate and refine the derived models, recheck the determined dependencies of indicators, and correct the proposed algorithm.

AUTHOR CONTRIBUTIONS

TM, LK, and AL contributed to conception and design of the study. AL and OP performed the statistical analysis. OP wrote the first draft of the manuscript. TM, LK, AL, and OP wrote sections of the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

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