https://doi.org/10.33271/nvngu/2023-6/100

A. Kwilinski[1,2],
orcid.org/0000-0001-6318-4001,
S. Kolosok[*3],
orcid.org/0000-0002-5133-9878,
A. Artyukhov[4],
orcid.org/0000-0003-1112-6891,
I. Vakulenko[3,5],
orcid.org/0000-0002-6994-833X,
Y. Kovalenko[3],
orcid.org/0000-0002-2111-9372

1 – WSB University, Dabrowa Gornicza, the Republic of Poland
2 – The London Academy of Science and Business, London, the United Kingdom of Great Britain and Northern Ireland
3 – BiEM, Sumy State University, Sumy, Ukraine
4 – University of Economics in Bratislava, Bratislava, the Slovak Republic
5 – Institute of Economic Research, Slovak Academy of Sciences, Bratislava, the Slovak Republic
* Corresponding author e-mail: kolosok@management.sumdu.edu.ua

SMART GRID PROJECTS IN THE PAN-EUROPEAN ENERGY SYSTEM

Purpose. To provide a comparative and comprehensive analysis of the smart grid projects funded by the H2020 ENERGY and FP7-ENERGY programs.

Methodology. As part of the text analysis, the authors evaluated smart grid projects' results in a sample using text mining methods. Based on statistical analysis and concept-based method, the most significant outcomes of smart grid projects were identified.

Findings. A detailed review of the results shows that project teams of the H2020 ENERGY and FP7-ENERGY programs mostly relied on the existing experience which helped to form further development for standardization of tools, conduct planning, or derive specific management actions aimed at smart energy consumption. The majority of these solutions were applied for digitalizing small commercial consumers and for integrating isolated renewable sources in the most effective way. The projects considered the possibilities of electric vehicles used to solve environmental problems and balancing unstable electricity production from renewable sources with Li-ion stationary batteries, tools for effective interaction of users of smart grids, and integration of isolated renewable sources in centralized energy networks.

Originality. Based on statistical and machine analysis, the most significant results of smart grid projects were identified. N-grams of expressed keywords used in the texts of project results were used to present and visualize the textual description of smart grid projects.

Practical value. The results might be helpful for the European policymakers and scientific advisers seeking to further promote and ameliorate the pan-European energy system.

Keywords: *energy grids, energy infrastructure, smart grids, information technologies, European Union*

Introduction. Today, deploying smart energy networks remains a crucial issue of the pan-European energy system. The essential need to improve information and communication technologies of the energy network, as well as energy storage systems, intelligent sensors, measurements, and intelligent control technologies, is mainly achieved by the European Union member states through financing priority energy reform projects.

It has been long acknowledged that the economic development leads to dynamic changes in the world thanks to the internationalization and expansion of commercial production. However, it is vital to find a balance between economic, ecological, political, and social trajectories of economic transformation in order to achieve the Sustainable Development Goals (SDGs) [1, 2].

Within this context, the smart grid concept represents an essential element of the future European energy system. There is a necessity for the existing power grid modernization and the smart grid deployment in Europe. Funding for new energy projects can, as a rule, speed up the integration and interoperability of networks [3, 4]. With all that, the modernization of energy grid information and communication technologies [5, 6], energy storage, smart sensing, metering, and intelligent management technologies are becoming essential for achieving energy efficiency and security, especially in the current turbulent times with the surging prices of oil and gas and geopolitical instability in Europe and around the world [7, 8].

It is predicted that in the future, European grids will evolve to become more environmentally and user-friendly, flexible, and cost-effective, will be more adaptive to low-carbon technologies and renewable energy resources use [9, 10]. The European Union widely supports such changes under the European Network of Transmission System Operators for Electricity thematic areas [11].

Literature review. The socio-ecological modifications in the energy sector change the local energy infrastructure. Decentralized energy systems are coming to the fore, capable of responding to an increase in the number of agents in the energy market, providing the possibility of flexible balancing of electricity, including renewable resources [12]. The share of renewable energy in gross final energy consumption is increasing from year to year. Therefore, multivariate analysis of carbon finance remains relevant as a tool for predicting and maximally mitigating negative influences. Since increased consumption of renewable sources is far from straightforward and has a mixed impact on security issues, new, more reliable energy policies are required [13].

The concept of green energy may help to achieve the highest environmental benefit. But it needs more effective cooperation between state and energy market players, implementation of infrastructure grid projects under the public-private partnership [14], local development financing determined to institutional changes in territorial communities, and flexible taxation.

The assessment of smart grids during their deployment and project scaling plays a significant role in today's energy sector. Lyulyov, et al. (2021) emphasize the importance of a systematic approach to evaluating smart grids and identifying their performance in different aspects, from economic to technical ones. This approach shows all the benefits of implementing smart grid projects, including those lost during the project evaluation, without considering its specificity and direct and indirect effects for various stakeholders. In an environment where the implementation of smart grids still faces many obstacles, it is extremely important to highlight all the current and long-term benefits of the project. This motivates project participants and stakeholders to invest in it and expand the smart energy grid.

The authors performed a comparative analysis of smart grid evaluation systems developed by leading energy agencies, relevant ministries, and companies involved in developing technologies for the energy sector. The authors identified seven areas of evaluation of smart grids that should be considered for a comprehensive assessment of their efficiency. These directions are The Stability of the Grid, Information Efficiency, Economic Efficiency, Technical Efficiency, Environmental Friendliness, Communication Efficiency, and Availability of Electric Transport Infrastructure.

Evaluating the smart energy grid project in each of these areas allows for an alternative assessment that differs from the one obtained due to the classical approach to assessing investment projects, where the project's economic efficiency comes first. It is considered the main motivator for the investor and determines the project's prospects.

The proposed approach by Lyulyov, et al. (2021) promotes a broader view of stakeholders with a vested interest in the project. In particular, providing a project assessment under the direction of Environmental Friendliness reveals the project's significance for the final consumer, households, and businesses through the mechanism of social responsibility. As a result of their interest, the project's importance increases for the authorities' representatives, who must meet the expectations of the voters who elect the authorities and the businesses on whose support it relies.

Such a motivation mechanism expands the possibilities of implementing projects for the development or modernization of the energy grids because it allows consideration of new schemes of co-financing or providing support to projects with an important social significance. This facilitates the construction of business models during the development of smart grids, which is one of the biggest challenges holding back the development of smart grids. However, despite the importance of this issue, in many cases, it does not find a solution during the preparation of smart grid projects. It is not reflected in most smart grid efficiency evaluation systems.

Evaluating the smart grid project in the direction of Information Efficiency pursues two tasks. First, the progressivity of the applied technologies, transforming the power grid into a smart grid, is evaluated. Secondly, such an assessment allows identifying gaps in modern information technologies and helps accelerate the development of information technologies needed in the energy market [5].

Lyulyov, et al. (2021) reviewed eight smart grid evaluation systems that are considered comprehensive and are used during the development of smart grid projects and monitoring their progress. The study highlights the lack of a universal evaluation system that perfectly considers all aspects of smart grids. In addition, the benchmarking showed that none of the existing evaluation systems follow sufficient indicators to assess the potential of smart grids for development and integration through business model creation. An exception may be the IBM Smart Grid Maturity Model, which recognizes the key role of a well-defined business model in driving the energy sector's growth through smart technologies.

However, the creation of such a business model involves the coordination of interests of interested parties. Therefore, forming a business model is an important factor in developing smart grids, and this aspect cannot be ignored in smart grid performance evaluation systems.

The integral assessment task is not to evaluate a separate smart grid project. Instead, this approach determines how successfully or not smart energy technologies are deployed in a certain region. Assessing the level of development of smart grids in a region or locality has several important goals and advantages:

1. Effective use of resources because smart grids allow optimizing energy production, distribution, and consumption. This helps to reduce energy losses, improve efficiency, and reduce energy supply costs, which positively impacts the region's economy.

2. Reducing energy consumption because smart grids minimize energy consumption by optimizing the operation of devices and systems in real-time. This helps reduce greenhouse gas emissions and improve the environmental situation.

3. Improvement of reliability through automatic detection and correction of malfunctions in the system.

4. Supporting renewable energy by integrating renewable energy sources, such as solar panels and wind turbines, into the electricity supply system, which contributes to the transition to more sustainable and environmentally friendly energy.

5. Improving the quality of service by providing users with more information and control over their energy consumption, which contributes to customer satisfaction.

6. Support for innovation, because smart grids require the development of new technologies and infrastructure, which can contribute to the development of the innovative sector and the creation of new jobs.

Therefore, assessing the level of development of smart grids is important to achieve these benefits and to ensure sustainable and modern energy supply systems in a region or locality [5].

The authors Kwilinski, et al. (2022) have formed a system of indicators for the assessment of smart grids for the creation of an integrative system of evaluation of smart grids. Using the developed approach for an integrative assessment of the development of smart grids can help determine priority projects, develop state and regional sectoral programs in the energy sector, and monitor the effectiveness of energy policy [14].

Typically, smart grids' projects are based on the assumption of economic motivation of smart grids end-users. However, in practice, consumer actions are not always financially justified. There is some passivity in their decisions, which significantly complicates predicting network development and electricity demand. Similar results were obtained earlier by Lazowski et al. on the example of a pilot project in Ontario (Canada). In their study, the authors saw that consumers' monetary motivation to use networks wisely was constrained by social and behavioral factors, exacerbated by differences in their energy cultures. That is, now an integrated approach is required to the configuration of smart grids, which considers many factors. The level of complexity of such systems is steadily increasing [15].

Alternatively, it is possible to transform such energy passivity of consumers within the citizens' energy communities. In such communities, prosumers actively stimulate the spread of green innovations, raise awareness of the benefits of green energy and decarbonization of energy systems. And if earlier projects in energy communities were mainly aimed at collective energy procurement or mastering energy-efficient technologies of its production, now the intelligent electrical control systems based on ICT use are gaining more and more development [16].

The success of consumers' use of such smart management systems directly depends on the degree of trust in the systems and compliance with consumers' aspirations in the implementation of smart grids. For example, the realization of the JEM ("Jouw Energy Moment") initiative by a Dutch electricity distribution system operator, that minimizing the negative impact on the grid has not been attractive enough for all members of this initiative [17].

Conditions for participants of the EcoGrid 2.0 project (Denmark) were also insufficiently acceptable. Several consumers entirely accepted and understood the principles of the project, according to which their automated houses were used to balance the energy system. However, most users still stuck to the condition that met only some criteria. The pilot group participants had questions about its reliability, security, and data protection [18].

And the results of the previous EU EcoGrid project were also mixed. During this project's deployment on some days, smart home consumers reacted sensitively to price factors in the system, and on others were not [19].

In general, according to a study by Hansen & Borup, the information support of experimental smart grid projects is still included simple interfaces. The projects considered by the authors had limited ICT functionality which partially took into account consumer behavior and did not have a systemic nature [20].

According to IqtiyaniIlham, et al. (2017), the first smart grid project in Europe was launched in 2001. This project involved the installation of smart meters in 12 EU countries, which helped to improve their energy efficiency. Smart meters reduced electricity consumption by up to 10 % in these countries [11].

Initiatives to deploy smart grids have been introduced at both the national and EU levels. A number of programs have been funded in the EU, including FP6, FP7, EEGI, etc. However, investments in developing smart grids between EU countries have been uneven. This has created problems for cross-border interaction, electricity trade, and technical and social aspects of smart grid development.

According to the Smart Grid Projects Outlook 2014, €3.15 billion was invested in 459 smart grid projects from 2002 to 2013. The average budget of a smart grid project was €6.86 million. Out of all 459 projects, 45.97 % were categorized as demonstration and deployment (D&D) and 54.03 % as research and development (R&D). 73.65 % of the total budget of all 459 smart grid projects was allocated to D&D funding and 26.35 % to R&D. According to Outlook, most projects were concentrated in five countries: Germany, Denmark, Italy, Spain, and France. The most active was the Danish company, which participated in 45 projects out of 459. 62.5 % of the projects on the Outlook 2014 list were national, with only 15.9 % having more than one partner. 37.5 % of projects were categorized as multinational. On average, each multinational project involved partners from 6 countries. The average duration of all projects described by Outlook was 2.75 years [11].

However, only 22 % of the total budget of smart grid projects was funded by the EU due to the general uncertainty of the results of smart grid projects. Thanks to the 6th EU Research Framework Program (FP6), eight smart grid projects have been invested for €38 million and 23 projects for €146 million under the Seventh Framework Program (FP7) of the European Community. The European Recovery Fund, the European Regional Development Fund, and the European Energy Research Alliance have invested €200 million in the development of smart grid projects [11].

Among the critical challenges to the deployment of smart grids in Europe, project participants mentioned the following:

1. The need for systematic integration between the physical and market levels to ensure interoperability of smart grid deployment.

2. Existence of regulatory barriers and need for incentives for consumers to deploy smart grid technologies.

3. Grid design and control system changes require technology maturity to balance all levels.

4. Low consumer awareness of the benefits and opportunities of smart grids.

To overcome the challenges and develop a common vision for the deployment of smart grids, the Smart Grid European Technology Platform was established by the European Commission in 2015. As part of the platform's work, a group of experts developed a roadmap and plan for the Smart Grid Task Force. Subsequently, the deployment of smart grids in Europe was supported by many initiatives, including the Smart Cities and Communities initiative, the European Electricity Grid Initiative, etc.

The successful deployment of smart grids depends on the systematic application of technologies that affect key components of electricity generation, distribution, and consumption:

1. Use of decentralized topologies (virtual power plants, microgrids).

2. Bi-directional communication (smart metering, distributed automated system for building communication between elements of smart grids).

3. Distributed automated systems (demand response, demand side management).

4. Advanced control techniques (wide-area measurement systems, distribution, outage and energy management systems, intelligent electronics devices, and advanced metering infrastructure).

5. Consumers' participation (smart home).

6. Interoperability frameworks (smart meter interface).

7. Electric transportation (electric vehicles, electric vehicle supply equipment, plug-in hybrid electric vehicles) [11].

Unsolved aspect of the problem. It is proved that the public investment in infrastructure projects causes productivity growth in the long run. Increasing green investment positive effect on the country's energy efficiency and the renewable energy sources share in total energy consumption. Countries develop and promote renewables through the renewable energy projects financing.

However, is this the case for smart grid projects funded to transition to sustainable energy under the H2020 ENERGY and the FP7-ENERGY programs? What are the main results of these projects? What are the differences in the timing and budgeting of these projects? All these issues need detailed consideration.

Purpose. Our paper provides a comparative and comprehensive analysis of the smart grid projects funded by the H2020 ENERGY and FP7-ENERGY programs.

Methods. Our study used the results of EU-funded projects since 1990, disseminated by the Community Research and Development Information Service (CORDIS). First, we were clustering the data using "results in brief" filters for smart grid projects funded by the H2020 ENERGY and the FP7-ENERGY programs. After filtering the data, we obtained a large list of projects. Second, we performed the analysis of project results also manually. The authors refined the results, which were duplicated or not related to the objectives of the study. During this iterative process, a final sample of 25 projects was created. The twenty projects in a sample were funded under the FP7-ENERGY program, and only five received financial support under the H2020 ENERGY program.

In the EU above € 130 million was spent on these projects, i.e., on average more than € 5 million per project was allocated. If one looks at the smart grid projects' geography, projects were coordinated mostly by organizations from Italy. These organizations distributed 21.2 percent of all budget funds. Interestingly, smart grid projects were coordinated by organizations from ten countries in the EU (Fig. 1).

In this manuscript, the authors considered specific cases and analyzed such project materials as "project information", "fact sheet" and "results in brief". A comparative analysis of project performance was performed to identify common features and differences in smart grid projects funded by the H2020 ENERGY and the FP7-ENERGY programs. Considering the "project information" and "fact sheet", the authors performed a time and cost analyses of the projects.

As part of the text analysis, the authors evaluated smart grid projects' results in a sample using text mining methods. A textual description in English was used to analyze the results of these projects. Based on statistical analysis and concept-based method, the most significant outcomes of smart grid projects were identified. Text preprocessing was performed using the capabilities of the "nltk" (natural language toolkit) library of the Python programming language (version 3.5).

In this way, the concept-based model helped identify the most significant conditions in terms of observation frequency. To eliminate noise in the results, the authors used a "stop-words" filter. Other text cleaning tools were not employed in this study (e.g., mentions, urls, punctuation, digits, stemming).

The N-Gram features were used to present and visualize text mining results. The Scikit-learn's "CountVectorizer" function was applied to form such type diagrams. The charts were constructed using "Plotly" text visualization tools. After removing stop words, unigrams were created containing the most common words in smart grid projects. Based on these methods, various aspects of smart grid projects were analyzed in the results section.

Results. The smart grid projects funded under the H2020 ENERGY, and the FP7-ENERGY programs have more than 11.5 years' timeline. The projects in a sample were implemented primarily during 2015–2016. In this period, thirteen projects were executed. The smallest number of projects was funded in 2019–2020. Only one project was finished at that period, the "PV-Prosumers4Grid" project.

Smart grid projects lasted 782.16 days on average, from 522 to 1435 days. However, the longest project in the sample is "SMARTGRIDS ERA-NET". Among the results of this project was the development of a scientific network aimed at smart-grid-related research.

The project budget is one of the determining factors for its successful operation. The EU-funded "ADDRESS" project

Table 1

Top 5 smart grid projects funded under the H2020 ENERGY and the FP7-ENERGY programmes

Acronym	Project budget (€)	Duration (days)	Project budget per day (€/day)	Coordinators (country)
ADDRESS	16,541 647.00	1306	12,665.89	Italy
RealValue	15,413 331.00	784	19,659.86	Ireland
PEGASE	13,593 188.80	1045	13,007.84	Belgium
EVOLVDSO	7,844 431.00	872	8,995.91	Italy
DISCERN	7,635 359.73	847	9,014.59	Germany

has the most significant budget between the smart grid projects in the sample (Table 1). The "ADDRESS" was implemented to build active distribution networks with the aggregator toolbox management system. This tool had comparatively better optimization on electricity prices, volumes and trading, electricity consumption, and market forecasting.

Most projects had a budget of up to € 6 million, and their implementation did not exceed 800 days (Fig. 2). The "SMARTGRIDS-ETPS-III" and "SMARTGRIDS-ETPS" were projects with the smallest budgets. Less than a million euros was spent on each of them. And if ones compute the day budget for the project "SMARTGRIDS-ETPS-III", it will be only € 974.38. This sum is the minimum day budget in this sample of projects.

Italian operator e-distribuzione S.p.A. for two projects used the largest share of the budget funds, 18.72 % (Table 2). The second in the list is RWE Deutschland Aktiengesellschaft, the German operator. This coordinator spent 14.58 % of all budget funds for the "G4V", "DISCERN" and "PLANGRIDEV" projects. And the third largest coordinator is Glen Dimplex Heating & Ven-tilation Ireland Unlimited Company, which shared 11.83 % of the budget for the "RealValue" project. The "RealValue" is the project with the second-largest budget volume out of all 25 projects in the sample. The Horizon 2020 "RealValue" project provided the development of smart electric thermal storage systems based on the cloud optimization engine.

Text analysis of smart grid projects results showed some differences in the total word frequency. If one will look at the descriptive statistics of "results in brief", then it will be seen that the results of H2020-EU projects were more described

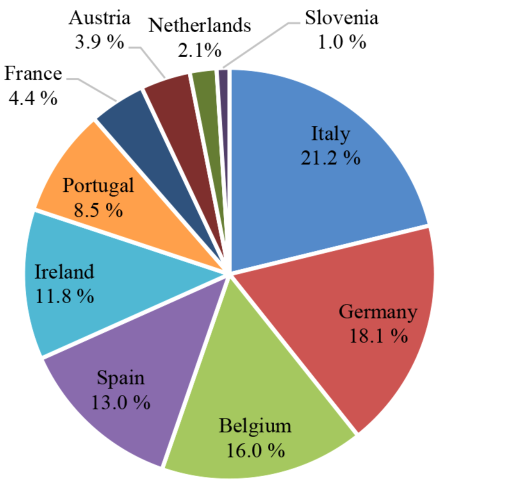

Fig. 1. Geographical distribution of smart grid project budgets funded under the H2020 ENERGY and the FP7-ENERGY Programmes

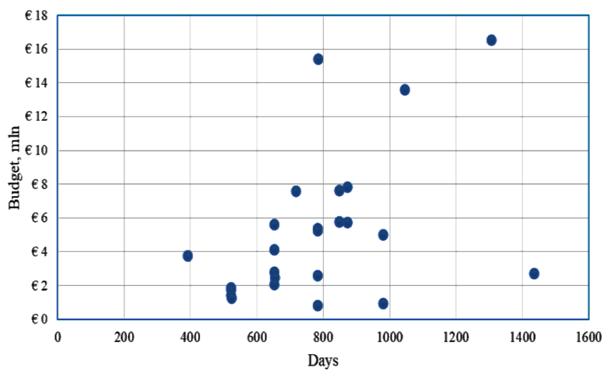

Fig. 2. The dot plot of the dependency between budget and duration of smart grid projects funded under the H2020 ENERGY and the FP7-ENERGY Programmes

Table 2

Main coordinators of smart grid projects funded under the H2020 ENERGY and the FP7-ENERGY programmes

Coordinator	Budget (mln €)	%	Number of projects	Projects' acronyms
e-distribuzione S.p.A. (Italy)	24.39	18.72	2	ADDRESS, EVOLVDSO
RWE Deutschland Aktiengesellschaft (Germany)	19.00	14.58	3	G4V, DISCERN, PLANGRIDEV
Glen Dimplex Heating & Ventilation Ireland Unlimited Company (Ireland)	15.41	11.83	1	RealValue
Tractebel Engineering (Belgium)	13.59	10.43	1	PEGASE
EDP Distribuição – Energia S.A. (Portugal)	5.78	4.44	1	SUSTAINABLE

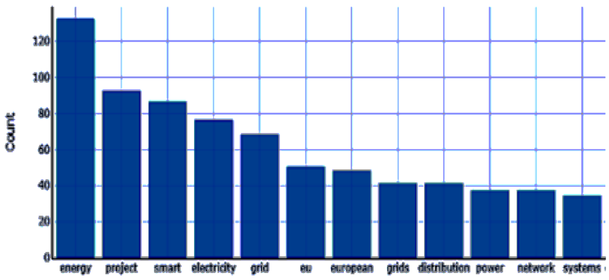

Fig. 3. The most common words for "results in brief" of smart grid projects (after stop words removing)

than the FP7-ENERGY (Table 3). The statistical variance of FP7-ENERGY projects' results specification is slightly higher also.

The frequency count analysis did not show unexpected outcomes. The top 15 words for "results in brief" of smart grid projects refer to the technological aspects of electricity grids (Fig. 3). Unigrams "energy", "project", "smart", "electricity" and "grid" occurs at least 60 times in results in brief. Additionally, among the common unigrams are the words "distribution", "network", "power", "systems", "developed", "technology".

All researched projects had some impact on sustainable technology development. But the priorities were usually different for the projects. Project teams mostly relied on existing experience, forming further developments to standardize tools, planning, or specific management actions aimed at smart energy consumption. In comparison, the "STALLION" and "STABALID" projects introduced standards for the European battery industry. The "OPEN METER" involved developing standards for implementing new infrastructure based on smart multi-metering technologies.

The "SMARTGRIDS ERA-NET", one of the longest-running projects and the related "SMARTGRIDS-ETPS-III" project were set up to stimulate and disseminate research to build smart energy infrastructure in Europe. The progress of visions and strategic documents in this area was among the "SMARTGRIDS-ETPS" results. Methodology and tools for cost-effective network operation were developed in the "DISCERN" project.

As for planning and managing sustainable transformation within smart grid development, project teams have created plenty tools. It is possible to name the instruments for distribution system operators ("PLANGRIDEV", "EVOLVDSO"), implements for control of the mass introduction of EVs, and PHEVs ("G4V"), and the charging stations for EVs ("INCH").

Also, in the projects, much attention was paid to the study on new technologies, their potential impact on existing power grids, the possibility of expanding the use of smart solutions among end-users. As well, the analyses of smart metering technologies ("Meter-ON"), of the EVs integration impact on the power grid ("COTEVOS"), and assessments of consumer involvement and interaction ("S3C") were conducted. The study on consumers and their energy consumption culture was carried out both in standard conditions and in isolated, so-called "smart islands" or "new European villages".

It is easier to trace the impact of prosumers on the energy grid and pricing mechanisms in isolated areas by comparing different European countries' results. In such "village", data was also collected for the "PV-Prosumers4Grid" project, which evaluated the active deployment of photovoltaic panels, energy storage devices, and EVs in the conditions of the existing energy market.

A bit more complete understanding of the project priorities is given by analyzing trigrams of their results, both before the extraction of stop words and after it. Among the most used trigrams in the description of results are such phrases as "renewable energy sources", "distribution system operators", "mall commercial consumers", "distributed energy resources", "electricity networks future".

It should be noted that the search phrase "renewable energy sources" was included in the results of nine out of 25 smart grid projects that were investigated. However, the context of this phrase was varied. The projects considered the possibilities of electric vehicles using to solve environmental problems ("G4V", "PLANGRIDEV") and balancing unstable electricity production from renewable sources with Li-ion stationary batteries ("STABALID"), tools for effective interaction of users of smart grids ("S3C"), and for integration isolated renewable sources in centralized energy networks ("SINGULAR", "SUSTAINABLE", "PLANGRIDEV", "DREAM", "EVOLVDSO").

Besides that, considering the trigram "distribution system operators" (DSOs), it is possible to group projects in the following areas as:

- deployment of grids, balancing and RES, forecasting and assessing the state, and scaling virtual power plants regarding DSOs ("SUSTAINABLE", "PLANGRIDEV", "EVOLVDSO");
- the same issues but considering DERs and EV (for example, this issue was considered during the implementation of the "PLANGRIDEV" project).

Deeper machine analysis of the actual results of smart grid projects allowed us to identify four main clusters of topics in projects results:

- the first smallest cluster of topics is related to procedures for risk testing batteries and vehicles for their proper integration into electrical grids;
- the second largest cluster of project results is related to the introduction of various aggregators-mediators for the proper interaction of consumers, distribution system operators (DSOs), and transmission system operators (TSOs);
- the third cluster of project results combines various platforms for secure communication of stakeholders in the field of smart networks, conducting relevant research on a smart European electrical infrastructure;
- and the results of the last fourth cluster mainly consist of the development of frameworks for the effective construction of modern European communities, taking into account the possibilities of collaborative energy consumption and the influence of prosumers.

Also, the number of commercial and technical solutions is noteworthy that have been brought to life with the help of smart grid projects. Both hardware and software tools should be noted. Most of these solutions were created to digitalize small commercial consumers and integrate isolated renewable sources effectively.

So, there were developed integrated hardware and software for users' energy management on electricity, heating, and cooling ("Socialsmartgrid", "GREENHP", "RealValue", "AirWatt"), residential energy demand tools ("ADDRESS") for commercial consumers.

And among the numerous deliverables of smart grid projects, it is worth to highlight smart tools for managing the European grid ("PEGASE"), PV tools enhancing integration with the grid ("PVCROPS") and solutions for managing distribution ("SUSTAINABLE"), tools for stabilizing intermittent RES supply and integration with existing networks ("SINGULAR", "DREAM").

Overall, the projects' outputs have prompted significant changes in European legislative, standardization, technological, and technical areas. The energy culture of small commercial consumers has also shifted up.

Conclusions. Our review and comprehensive analysis of the results of European smart grid projects is necessary to understand the trajectory of sustainable technological development in the energy sector, areas of adaptation of green innovations, and enhanced renewable energy sources. The energy market development strategy goals are in line with harmonizing European standards of energy regulation, energy-saving, and the construction of a sustainable energy system. Funding for smart grid projects has its advantages in achieving sustainable development goals and a modern vision of network development.

Applying text mining techniques for the selected smart grid projects according to H2020 ENERGY and the FP7-ENERGY programs, their results were investigated to explain the directions of technological development. According to our results, the most used trigrams in describing the results are such phrases as "renewable energy sources", "distribution system operators", "small commercial consumers", "distributed energy resources", "electricity networks future".

Speaking about the pathways for further research, we can suggest a more detailed review of the results that would not mostly rely upon the existing experience but would rather form further developments to standardize tools, planning, or specific management actions aimed at smart energy consumption. Moreover, it is also possible to highlight the number of new commercial and technical solutions in the projects. Both hardware and software tools were made under financing smart grid projects. Most of these solutions were created to digitalize small commercial consumers and to integrate isolated renewable sources effectively.

Acknowledgments. *Authors would like to acknowledge the copyright holder: © European Union, 1994–2023 as well as the source of the extracted data which is CORDIS.*

Funding: This research was funded by the Ministry of Education and Science of Ukraine (grant numbers: 0123U101920, 0122U000788, and 0122U000769) and the CARA.

The project was funded by the European Union's Horizon 2020 Research and Innovation Programme on the basis of the Grant Agreement under the Marie Skłodowska-Curie funding scheme No. 945478-SASPRO 2.

The article expresses only the authors' views, neither the REA nor the Commission are accountable for any use of the information contained therein.

References.

1. Mentel, G., Vasilyeva, T., Samusevych, Y., Vysochyna, A., Karbach, R., & Streimikis, J. (2020). The evaluation of economic, environmental and energy security: Composite approach. *International Journal of Global Environmental Issues*, *19*(1-3), 177-195. Retrieved from http://www.inderscience.com/ijgenvi.

2. Vasylieva, T., Pavlyk, V., Bilan, Y., Mentel, G., & Rabe, M. (2021). Assessment of energy efficiency gaps: The case for Ukraine. *Energies*, *14*(5). https://doi.org/10.3390/en14051323.

3. Mentel, G., Vasilyeva, T., Samusevych, Y., & Pryymenko, S. (2018). Regional differentiation of electricity prices: Social-equitable approach. *International Journal of Environmental Technology and Management*, *21*(5-6), 354-372. https://doi.org/10.1504/IJETM.2018.100583.

4. Kolosok, S., Vasylieva, T., & Lyeonov, S. (2021). Machine analysis of the UK electrical energy initiatives based on the e-petitions to the UK government and parliament. *CEUR Workshop Proceedings*, *2870*, 1562-1573. Retrieved from https://ceur-ws.org/Vol-2870/paper116.pdf.

5. Lyulyov, O., Vakulenko, I., Pimonenko, T., Kwilinski, A., Dzwigol, H., & Dzwigol-Barosz, M. (2021). Comprehensive assessment of smart grids: Is there a universal approach? *Energies*, *14*(12), 3497. https://doi.org/10.3390/en14123497.

6. Colak, I., Sagiroglu, S., Fulli, G., Yesilbudak, M., & Covrig, C. F. (2016). A survey on the critical issues in smart grid technologies. *Renewable and Sustainable Energy Reviews*, *54*, 396-405. https://doi.org/10.1016/j.rser.2015.10.036.

7. Vasilyeva, T., Kuzmenko, O., Bozhenko, V., & Kolotilina, O. (2019). Assessment of the dynamics of bifurcation transformations in the economy. *CEUR Workshop Proceedings*, 2422, 134-146. Retrieved from https://www.scopus.com/record/display.uri?eid=2-s2.0-85071124329&origin=resultslist.

8. Tu, C., He, X., Shuai, Z., & Jiang, F. (2017). Big data issues in smart grid–A review. *Renewable and Sustainable Energy Reviews*, *79*, 1099-1107. https://doi.org/10.1016/j.rser.2017.05.134.

9. Bilan, Y., Srovnalã-KovÃi, P., Streimikis, J., Lyeonov, S., Tiutiunyk, I., & Humenna, Y. (2020). From shadow economy to lower carbon intensity: Theory and evidence. *International Journal of Global Environmental Issues*, *19*(1-3), 196-216. Retrieved from http://www.inderscience.com/ijgenvi.

10. Letunovska, N., Saher, L., Vasylieva, T., & Lieonov, S. (2021). Dependence of public health on energy consumption: A cross-regional analysis. *E3S Web of Conferences*, *250*, 04014. https://doi.org/10.1051/e3sconf/202125004014.

11. IqtiyaniIlham, N., Hasanuzzaman, M., & Hosenuzzaman, M. (2017). European smart grid prospects, policies, and challenges. *Renewable and Sustainable Energy Reviews*, *67*, 776-790. https://doi.org/10.1016/j.rser.2016.09.014.

12. Adil, A. M., & Ko, Y. (2016). Socio-technical evolution of Decentralized Energy Systems: A critical review and implications for urban planning and policy. *Renewable and Sustainable Energy Reviews*, *57*, 1025-1037. https://doi.org/10.1016/j.rser.2015.12.079.

13. Lucas, J. N. V., Francés, G. E., & González, E. S. M. (2016). Energy security and renewable energy deployment in the EU: Liaisons Dangereuses or Virtuous Circle? *Renewable and Sustainable Energy Reviews*, *62*, 1032-1046. https://doi.org/10.1016/j.rser.2016.04.069.

14. Kwilinski, A., Lyulyov, O., Dzwigol, H., Vakulenko, I., & Pimonenko, T. (2022). Integrative smart grids' assessment system. *Energies*, *15*(2), 545. https://doi.org/10.3390/en15020545.

15. Lazowski, B., Parker, P., & Rowlands, I. H. (2018). Towards a smart and sustainable residential energy culture: Assessing participant feedback from a long-term smart grid pilot project. *Energy, Sustainability and Society*, *8*(1), 1-21. https://doi.org/10.1186/s13705-018-0169-9.

16. Van Summeren, L. F., Wieczorek, A. J., Bombaerts, G. J., & Verbong, G. P. (2020). Community energy meets smart grids: Reviewing goals, structure, and roles in Virtual Power Plants in Ireland, Belgium and the Netherlands. *Energy Research & Social Science*, *63*, 101415. https://doi.org/10.1016/j.erss.2019.101415.

17. Smale, R., Spaargaren, G., & van Vliet, B. (2019). Householders co-managing energy systems: space for collaboration? *Building Research & Information*, *47*(5), 585-597. https://doi.org/10.1080/09613218.2019.1540548.

18. Pallesen, T., & Jacobsen, P. H. (2018). Solving infrastructural concerns through a market reorganization: A case study of a Danish smart grid demonstration. *Energy research & social science*, *41*, 80-88. https://doi.org/10.1016/j.erss.2018.04.005.

19. Le Ray, G., Larsen, E. M., & Pinson, P. (2018). Evaluating price-based demand response in practice – With application to the EcoGrid EU Experiment. *IEEE transactions on smart grid*, *9*(3), 2304-2313. https://doi.org/10.1109/TSG.2016.2610518.

20. Hansen, M., & Borup, M. (2018). Smart grids and households: how are household consumers represented in experimental projects? *Technology Analysis & Strategic Management*, *30*(3), 255-267. https://doi.org/10.1080/09537325.2017.1307955.

Проєкти розумних мереж у загальноєвропейській енергетичній системі

О. С. Квілінський[1,2], *С. І. Колосок*[*3], *А. Є. Артюхов*[4], *І. А. Вакуленко*[3,5], *Є. В. Коваленко*

1 – Академія ВСБ, м. Домброва-Гурнича, Республіка Польща

2 – Лондонська академія науки і бізнесу, м. Лондон, Сполучене Королівство Великої Британії та Північної Ірландії

3 – ННІ БіЕМ Сумського державного університету, м. Суми, Україна

4 – Економічний університет у Братиславі, м. Братислава, Словацька Республіка

5 – Інститут економічних досліджень Словацької академії наук, м. Братислава, Словацька Республіка

[*] Автор-кореспондент e-mail: kolosok@management.sumdu.edu.ua

Мета. Провести порівняльний і всебічний аналіз проєктів розумних мереж енергетичної системи, що фінансуються програмами H2020 ENERGY і FP7-ENERGY.

Методика. У рамках аналізу тексту автори оцінили результати проєктів розумних мереж у вибірці за допомогою методів інтелектуального аналізу тексту. На основі статистичного аналізу й концептуального методу були визначені найбільш значущі результати виконання проєктів розумних мереж.

Результати. Детальний аналіз результатів показує, що команди проєктів програм H2020 ENERGY і FP7-ENERGY здебільшого покладалися на наявний досвід, що допоміг сформувати подальший розвиток для стандартизації інструментів, провести планування або вивести конкретні управлінські дії, спрямовані на розумне споживання енергії. Більшість цих рішень було застосовано для цифровізації невеликих комерційних споживачів і для інтеграції ізольованих відновлюваних джерел найбільш ефективним способом. У проєктах розглядалися можливості використання електромобілів для вирішення екологічних проблем і балансування нестабільного виробництва електроенергії з відновлюваних джерел за допомогою літій-іонних стаціонарних акумуляторів, інструментів ефективної взаємодії користувачів розумних мереж, інтеграції ізольованих відновлюваних джерел у централізовані енергетичні мережі.

Наукова новизна. На основі статистичного й машинного аналізу були визначені найбільш значущі результати виконання проєктів розумних мереж. N-грами виражених ключових слів, що використовуються в текстах результатів проекту, були використані для представлення й візуалізації текстового опису проєктів розумних мереж.

Практична значимість. Результати можуть бути корисними для європейських політиків і наукових консультантів, які прагнуть подальшого розвитку та покращення загальноєвропейської енергетичної системи.

Ключові слова: *енергетичні мережі, енергетична інфраструктура, розумні мережі, інформаційні технології, Європейський Союз*

The manuscript was submitted 20.07.23.