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The modern capabilities of monitoring of sustainable and environmental development of the energy economy based on big data and datasets

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1 Introduction

The relevance of this study is explained by the fact that the environmental friendliness of energy is defined as its key benchmark by the Sustainable Development Goal 7 (SDG 7) (Ceglia et al., 2022; Chang et al., 2022; Pandey and Asif, 2022; Taskin et al., 2022). The problem is that sustainability and environmental friendliness of energy are multifaceted, which makes it difficult to quantify them (Popkova et al., 2021; Popkova and Sergi, 2021; Shabaltina et al., 2021; , 2022). To date, many indices have been calculated that directly or indirectly reflect the sustainability and environmental friendliness of energy (Sisodia et al., 2020; Štreimikienė et al., 2022; Teichmann et al., 2020), as well as many individual statistical indicators, but a systematic understanding of it has not yet been formed (Gallo et al., 2020; Ratner et al., 2021; Ratner et al., 2022).

In the existing literature, authors such as Hao (2022), Kluczek and Gladysz (2022), Romdhane et al. (2022), Xie (2022) proposed many methodological developments to improve the assessment of the energy economy, but no clear idea has been formed on how to implement them in practice. The calculated values of the composite indices on the example of individual countries cannot be used for analysis on the scale of the global energy economy, which does not allow international comparisons (de Oliveira Gabriel et al., 2022; Rink et al., 2022). Therefore, methodological developments should be supplemented with advanced technical solutions for their implementation (Bionaz et al., 2022; Haoyang et al., 2022).

To solve this problem, this paper suggests using Big Data and conducting dataset monitoring of sustainable and environmentally friendly development of the energy economy. The purpose of the article is to identify modern capabilities for monitoring of the sustainable and environmentally friendly development of the energy economy based on Big Data and datasets, as well as to develop recommendations for their implementation in practice. The originality of the article lies in the fact that it offers not only methodological but also complementary technical recommendations for improving the monitoring of sustainable and environmentally friendly development of the energy economy based on Big Data and datasets.

The paper's contribution to the literature consists in the development of a new approach to the monitoring of sustainable and environmental development of the energy economy, the specific features and advantages of which are, first, the use of serious mathematical tools—structural equation modelling—which allows for the transition from onedimensional (as in regular, simple indices) to multi-dimensional evaluation of sustainability and environmental friendliness of the energy economy. Second, the use of the leading technologies—big data and datasets—allows achieving unequalled high speed, precision and correctness (full objectivity) of evaluation.

Due to the above specifics and advantages, the authors' approach allows determining the level of sustainability and environmental friendliness of the energy economy (SDG 7) and determining the causal connections of the achievement of this level: revealing the factors of its achievement [Sustainable cities and communities (SDG 11) and Responsible production and consumption (SDG12)] and consequences (Climate action—SDG 13) and preservation of eco-systems and protection of biodiversity (SDG 14 and SDG 15).

The issues of environmental monitoring of the energy economy have been covered in detail in the existing literature. Kizielewicz (2022) analysed the scientific basis of the monitoring of energy efficiency and the Environmental Ship Index by cruise seaports in Northern Europe. Amerson et al. (2022) proposed recommendations on monitoring of the environment for marine energy development that considers life cycle sustainability.

Mataloto et al. (2021) developed 3D IoT system for the environmental and energy consumption monitoring system. Glinskii et al. (2020) presented their view of the prospects for the development of monitoring of the environment in the vicinity of nuclear energy facilities. Can (2019) discovered the risks that are based on the aerial photography that is used in photogrammetric monitoring maps for environmental wind power energy plant projects.

Cai et al. (2019) analysed wireless sensor network node energy technology for environmental monitoring. Pereira et al. (2022) proposed a promising data model and file format for representing and storing high-frequency energy monitoring and disaggregation datasets. Rahmani et al. (2022) recommended an energy-aware and Q-learning-based area coverage for the systems of monitoring of oil pipeline with the use of sensors and the Internet of Things.

The conducted content analysis of the existing literature revealed three disadvantages of monitoring of the sustainable and environmentally friendly development of the energy economy based on the existing approach to its implementation. The first disadvantage is the compartmentalization and incompatibility of indicators of sustainability and environmental friendliness of the energy economy. In the existing literature, Amir and Khan (2022), Gunnarsdottir et al. (2022), Klemm and Wiese (2022), Reynolds et al. (2022), Schöne et al. (2022) propose methods involving the use of indicators from different empirical databases. These indicators have different units of measurement. Some indicators are statistical (quantitative), while others are obtained by expert means (qualitative) (Çağman et al., 2022; Laing et al., 2022; Maki et al., 2022). The evaluation results based on such methods are not accurate enough and not reliable enough, therefore, there is a high probability of errors and misinterpretations (Magrini et al., 2022; Pereira et al., 2022; Rahmani et al., 2022).

The second disadvantage is the uncertainty of cause-and-effect relationships of sustainable and environmentally friendly development of the energy economy. The methods proposed in the works of Huang et al. (2022), Sarwar (2022), Shah and Longsheng (2022), Yamaka et al. (2022) focused on evaluating only the results (for example, the energy efficiency of economic growth, the share of "clean" energy in the structure of energy consumption). At the same time, the factors for achieving these results remain unclear and break the limits of existing methods. The results of the assessment according to existing methods do not provide the necessary support for the management of sustainable and environmentally friendly development of the energy economy (Kang et al., 2022; Ratner et al., 2022; Vu et al., 2022).

The third disadvantage focuses on low technical efficiency. The methods described in the works of Bilal et al. (2022), Wang et al. (2022), Yang et al. (2022) involved the so-called manual collection and analysis of data from many different sources. In this regard, the process of assessing the sustainability and environmental friendliness of the development of the energy economy is long, time-consuming and greatly affected by the "human factor" (the risks of the subjectivity of the assessment) (Li et al., 2022; Ullah et al., 2022; Zhang et al., 2022). The ambiguity of the prospects for overcoming these disadvantages is a research gap that is being filled in this article through a review of current opportunities for improving the scientific and methodological approach to monitoring of the sustainable and environmentally friendly development of the energy economy based on Big Data and datasets.

2 Materials and methods

To overcome the disadvantages of the existing approach, a new (alternative) system approach is proposed to conduct automated monitoring of sustainable and environmentally friendly development of the energy economy based on Big Data and datasets. The following recommendations are proposed for monitoring based on the authors' approach. Firstly, it is recommended to rely on the statistics of the UNDP (2022), since it most accurately and reliably characterizes the sustainability and environmental friendliness of the development of the energy economy, and also contains comparable indicators (the results of the implementation of various SDGs).

Secondly, it is proposed to take into account not only the result (SDG 7) but also the factors of its achievement and the consequences of sustainable and environmentally friendly development of the energy economy. The factors are the sustainability of cities and populated areas (SDG 11) and the responsibility of production and consumption (SDG 12). The consequences are the fight against climate change (SDG 13), the conservation of ecosystems and the protection of biodiversity (SDG 14 and SDG 15).

Thirdly, it is recommended to use an improved algorithm for monitoring of the sustainable and environmentally friendly development of the energy economy based on Big Data and datasets. At the first stage of the proposed algorithm, data is collected for each of the above SDG—a set of data is generated (for example, on a large sample of countries or a number of periods). The second stage is associated with the analysis of variation (the spread of values of indicators). At the third stage, the relationship of indicators is evaluated and their network structure is formed (based on Big Data technologies). The fourth stage is the calculation of the integral indicator of sustainability and environmental friendliness of the energy economy with a systematic account of the values of indicators and their interrelations.

2.1 The model of sustainable and green development of the energy economy in the EAEU in 2021

In the Eurasian Economic Union (EAEU), a lot of attention is paid to the issues of sustainable and green development of the energy economy. There is a special Energy Department with the Eurasian Economic Commission (2022). The implemented initiatives include the provision of energy security, unification of the legal regulation of energy resources exchange trading and digital development of the energy economy based on Smart Grid and EnergyTech. All participants of the EAEU share the strategic initiatives on the achievement of carbon neutrality of the economy by 2050.

For example, the Kyrgyz Republic started in 2022 the Project on modernisation and sustainability of the energy sector, aimed at improving the financial state and operational effectiveness of the sector of electric energy and strengthening the mechanisms of social protection to assuage the potential influence of reforms on consumers. The project is implemented with financial and coordination support from the World Bank and SECO development of hydropower and solar energy. This project is expected to pave the way to sustainable and affordable use of renewable sources of energy (World Bank, 2022).

Kazakhstan actively develops alternative energetics by the example of successful developed countries. For example, nuclear power in Kazakhstan is developed based on the leading experience of France (Centre for business information Kapital, 2022). The model of sustainable and green development of the energy economy in the EAEU in 2021 implies close cooperation between the EAEU members at all stages of the chain of value-added creation in energetics: from production to consumption. This model is based on the unification of efforts and the development of responsible communities, as well as responsible energy companies.

2.2 Dataset-countries monitoring of sustainable and environmentally friendly development of the energy economy in the EAEU countries in 2021

To demonstrate the possibilities of the proposed approach, we conducted a dataset monitoring of sustainable and environmentally friendly development of the energy economy in 2020 in the Eurasian Economic Union (EAEU) (Regions used for the SDR: E. Europe & C. Asia). At the same time, we rely on the dataset framework "Corporate Social Responsibility, Sustainable Development and Combating Climate Change: Simulation and Neural Network Analysis in the Regions of the World—2020" (Institute of Scientific Communications). There is a shortage of data on SDG 14 in the EAEU countries, so it is not taken into account in the ongoing monitoring. The study is based on the official data set of the UNDP (2022) for 2021, according to which:

→ In Armenia, SDG 7 is estimated at 94.821 points, SDG 11 at 76.445 points, SDG 12 at 88.685 points, SDG 13 at 93.073 points and SDG 15 at 61.792 points;
→ In Belarus, SDG 7 is estimated at 90.59 points, SDG 11 at 76.084 points, SDG 12 at 86.433 points, SDG 13 at 88.838 points and SDG 15 at 78.601 points;
→ In Kazakhstan, SDG 7 is estimated at 86.528 points, SDG 11 at 83.715 points, SDG 12 at 74.854 points, SDG 13 at 74.854 points and SDG 15 at 56.959 points;
→ In Kyrgyzstan, SDG 7 is estimated at 89.752 points, SDG 11 at 88,656 points, SDG 12 at 86.505 points, SDG 13 at 86,505 points and SDG 15 at 71.352 points;
→ In Russia, SDG 7 is estimated at 90.823 points, SDG 11 at 85,867 points, SDG 12 at 76.669 points, SDG 13 at 76.669 points and SDG 15 at 66.183 points.

Based on the authors' approach, the structural equation modelling (SEM) method provides a case example of monitoring of the sustainable and environmentally friendly development of the energy economy in the EAEU countries (Figure 1).

2.2.1 Source: Authors' work

Figure 1 shows that in the EAEU countries in 2021, in general, there is a fairly high level of sustainability and environmental friendliness of the energy economy. It is defined through the product of arithmetic averages for the considered SDGs with their correlation coefficients with SDG 7 as follows:

$[(82.1532*(-0.5233)) + (82.6291*0.6967) + 90.5029 + (81.7441*0.7298) + (66.9774*0.1497)]/5 = [-42.994 + 57.565 + 90.50 + 59.654+41.182]/5 = 205.91/5 = 41.1820$ points (with a maximum value of 100 points).

These results were obtained from the methodological point of view–based on the authors' methodological developments (the systems approach and an improved algorithm from the second section of this paper); and from the methodical point of view–based on the capabilities of modern digital technologies: big data and datasets. The statistics on the EAEU countries are unified in one dataset, which is used–with the technology of big data processing–to perform automatised calculations. Thus, a SEM model was obtained.

The analysis of cause-and-effect relationships revealed that sustainable cities and settlements make an insufficient contribution to the sustainable and environmentally friendly development of the energy economy in the EAEU countries. The small contribution of this development to the protection of ecosystems and the conservation of biodiversity has also been established. In this regard, to increase the sustainability and environmental friendliness of the energy economy in the EAEU countries, it is recommended to pay increased attention to the practical implementation of SDG 12 and SDG 15.

2.3 Forecast for sustainable and green development of the energy economy in the EAEU for the period until 2024

To specify the connections between the selected indicators, we identify the regression dependencies of sustainable and green development of the energy economy in the EAEU in 2021. As a result, it is determined that affordability and "cleanliness" of energy in the EAEU grow by 0.32 points in the case of the development of responsible production and consumption by one point (SDG 7 = 63.71 + 0.32*SDG 12). It is also determined that the growth of affordability and "cleanliness" of energy in the EAEU by one point lead to the growth of results in the fight against climate change by 3.44 points (SDG 13 = -229.68 + 3.44*SDG 7) and the growth of success in the preservation of land ecosystems and protection of biodiversity by 0.42 points (SDG 15 = 28.57 + 0.42*SDG 7).

Based on the arithmetic mean for the EAEU (82.63 points) and standard deviation (6.37 points), we perform a scenario analysis of responsible production and consumption, using the Monte Carlo method. 100 random numbers are generated, and their histogram

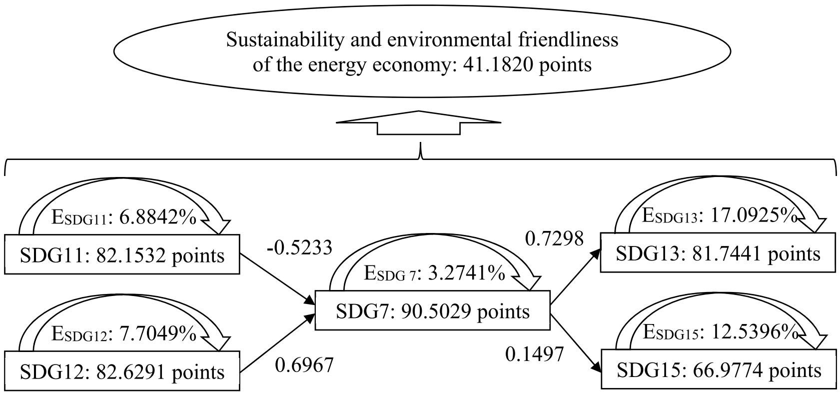

FIGURE 1
A case example of monitoring of the sustainable and environmentally friendly development of the energy economy in the EAEU countries.

is obtained, according to which the most probable forecast value (with the probability of 24%) is 86.70 points, which is 4.96% higher than the 2021 level (realistic scenario).

In the least favourable (pessimistic) scenario (probability: 6%), the level of development of responsible production and consumption will drop down to 78.79 points, which is 4.65% lower than the 2021 level. In the most favourable (optimistic) scenario (probability: 5%), the level of development of responsible production and consumption will grow up to 94.62 points, which is 14.51% higher than the 2021 level.

Based on the revealed regression dependencies of the variables, we compile a forecast for sustainable and green development of the energy economy in the EAEU for the period until 2024. In the realistic scenario, affordability and "cleanliness" of energy in the EAEU until 2024 will grow up to 91.82 points (+1.46%). Due to this, the results in the fight against climate change will grow up to 86.29 points (+5.56%), and success in the preservation of land ecosystems and protection of biodiversity will grow up to 67.54 points (+0.84%).

In the pessimistic scenario, affordability and "cleanliness" of energy in the EAEU until 2024 will reduce to 89.26 points (−1.38%). Due to this, the results in the fight against climate change will reduce to 77.46 points (−5.24%), and success in the preservation of land ecosystems and protection of biodiversity will reduce to 66.45 points (−0.79%). This scenario may be implemented in the case of a global energy crisis, the preconditions for which are observed in 2022.

In the optimistic scenario, affordability and "cleanliness" of energy in the EAEU until 2024 will grow up to 94.39 points (+4.30%). Due to this, the results in the fight against climate change will grow up to 95.129 points (+16.37%), and success in the preservation of land ecosystems and protection of biodiversity will grow up to 68.63 points (+2.46%). This scenario may be implemented in the case of a successful resolution of the international sanction crisis until 2024.

3 Results and discussion

The key results of the performed research are as follows: first, a model of sustainable and green development of the energy economy in the EAEU in 2021 was created–it reflects the organisational and legal foundations of environmental management in this integration union of countries. The model discovered the unification of managing the sustainable and environmental development of the energy economy among the participants of integration unions of countries (by the example of the EAEU). Therefore, monitoring of the results of this management should be performed at the supranational level, since this will allow identifying not only private (achieved in certain participating countries) but also common (achieved by the integration union on the whole) results, as well as the synergetic effect of integration, which consists in the accelerated implementation of the SDGs.

Second, monitoring of sustainable and environmentally friendly development of the energy economy in the EAEU countries in 2021 (based on the dataset countries) was performed. We discovered a high level of sustainable and environmental development of the energy economy, demonstrated by the achieved serious results in the implementation of SDG 7: 94.821 points in Armenia, 90.590 points in Belarus, 86.528 points in Kazakhstan, 89.752 points in Kyrgyzstan and 90.823 points in Russia.

On the whole (on average) for the EAEU, the results in the achievement of SDG 7 equals 90.503 points. Given the fact that the maximum possible value is 100 points, the sustainability and environmental friendliness of the energy economy in the EAEU exceeds 90%. This is just the beginning of the Decade of Action, and the variation among participating countries is very low (3.274%). This is a sign of uniformity of the results of the achievement of SDG 7 among the EAEU members and the reliability of the monitoring results (they could be applied to the entire integration union).

The case example of the monitoring of sustainable and environmental development of the energy economy in the EAEU also demonstrated a synergetic effect: the sustainable and environmental development of the energy economy supports–by 41.182%—the development of the green economy in the EAEU, i.e., the results on SDG 11, SDG 12, SDG 13 and SDG 15. Therefore, the sustainable and environmental development of the energy sphere in the EAEU facilitates the development of sustainable territories, responsible production and consumption, the fight against climate change and the preservation of land ecosystems.

Third, a forecast for sustainable and green development of the energy economy in the EAEU for the period until 2024 was prepared. Due to the comprehensiveness of the monitoring (consideration of the connections between the SDGs of the green economy), the forecast, which is based on it, reflected not only the expected growth of the result of the implementation of SDG 7 (+4.30%—up to 94.39 points–increase in accessibility and cleanliness of energy by 2024) but also the expected advantages for other Sustainable Development Goals. In particular, for the fight against climate change (+16.37% for SDG 13, up to 95.129 points) and for biodiversity protection (+2.46% for SDG 15, up to 68.63 points).

The discovered advantages belong to the synergetic effect of the sustainable and environmental development of the energy economy and will be added to independent initiatives on the implementation of the considered SDGs. Due to the discovered synergetic effect, the totality of SDGs of the green economy, in the case of the optimistic scenario, might be fully achieved even before 2030, i.e., exceeded in the Decade of Action.

Thus, the increased completeness and correctness of the results of the monitoring, as well as the increased precision and consistency of forecasts that are based on them are the advantages (proved in this paper), which point at the preference for the use of big data and datasets during the monitoring of sustainable and environmental development of the energy economy.

The contribution of the article to the literature is the improvement of the scientific and methodological approach to monitoring of the sustainable and environmentally friendly development of the energy economy. Unlike Gunnarsdottir et al. (2022), Klemm and Wiese (2022), Reynolds et al. (2022), Schöne et al. (2022), it is proposed not to collect data from different sources, but to rely on ready-made datasets in which all indicators are comparable, for example, on the UNDP (2022) dataset. This improves the accuracy of the assessment. In contrast to Huang et al. (2022), Sarwar (2022), Shah and Longsheng (2022), Yamaka et al. (2022), it is proved that there is a need in the monitoring process to take into account not only the results achieved but also the factors and consequences of sustainable and environmentally friendly development of the energy economy. At the same time, the interrelated SDGs are considered systematically (SDG 11-12, SDG 7, SDG 13–15). This ensures the completeness of the assessment and the increased practical significance of its results.

Unlike Bilal et al. (2022), Wang et al. (2022), Yang et al. (2022), it is recommended to use the improved algorithm for monitoring of the sustainable and environmentally friendly development of the energy economy based on Big Data and datasets. Reliance on high technologies and advanced automation tools makes it possible to model the relationships of indicators and on their basis to conduct an integrated assessment of the sustainability and environmental friendliness of the energy economy. This ensures the acceleration and simplification of the evaluation procedure, as well as guarantees the reliability of its results (objectivity due to the reduction of dependence on the "human factor").

4 Conclusion

The main contribution of this paper to the literature lies in revealing the prospects for the improvement of monitoring of sustainable and environmental development of the energy economy. As shown in the paper, these prospects are connected with the use of Big Data and datasets, which allow raising the flexibility of monitoring. This ensures more accurate and informative results, which are useful for environmental management.

Based on the results of the study, many disadvantages of monitoring of the sustainable and environmentally friendly development of the energy economy based on the existing approach to its implementation are substantiated: 1) fragmentation and incomparability of the indicators of sustainability and environmental friendliness of the energy economy; 2) uncertainty of the causal connections of the sustainable and environmental development of the energy economy; 3) low technical effectiveness. The authors' vision of modern capabilities of overcoming these disadvantages with the help of improved methods and the use of advanced technical means is presented.

The improved algorithm of monitoring of the sustainable and environmental development of the energy economy based on big data and datasets optimised the methodology for evaluating the results of this development. The advantage of the authors' methodological recommendations is their analysing of the sustainability and environmental friendliness of the energy economy from the position of the SDGs and taking into account the specified results on the SDGs in quantitative terms.

The novelty and originality of the authors' methodological development lies in its taking into account the systemic connection between the SDGs of the green economy. Due to this, the monitoring allows–for the first time–determining not only own results of the energy economy (SDG 7) but also its contribution to the development of sustainable territories (SDG 11), responsible production and consumption (SDG 12), fight against climate change (SDG 13) and preservation of land ecosystems (SDG 15).

From the technical point of view, the authors' methodological development can be implemented with the help of modern digital opportunities–big data and datasets. Their application for the monitoring of sustainable and environmental development of the energy economy simplifies and accelerates the process of monitoring (due to automatization) and ensures consistency, as well as raises the completeness and correctness of its results and precision of forecasts based on them. As a practical implication of this study, applied recommendations and a systematic approach to conducting automated monitoring of sustainable and environmentally friendly development of the energy economy based on Big Data and datasets have been developed.

The advantages of the new approach are the following: it has clarified the list of performance indicators; has improved the monitoring algorithm; it is universal (suitable for different countries of the world). The developed approach allows the most complete and effective use of modern monitoring capabilities for sustainable and environmentally friendly development of the energy economy based on Big Data and datasets. The approbation of the approach by the case example of the EAEU countries made it possible to systematically assess the sustainability and environmental friendliness of the energy economy, as well as to offer recommendations for improving its management (for economic policy).

The theoretical significance and value of the results obtained consist in their demonstrating a successful model of sustainable and green development of the energy economy in the EAEU in 2021 and the case experience of the practical implementation of this model by the example of Kazakhstan and Kyrgyzstan. The practical significance of the research is due to the compiled forecast for sustainable and green development of the energy economy in the EAEU until 2024 demonstrating the prospects for this development.

The forecast outlined the alternative scenarios of sustainable and green development of the energy economy and reduced the uncertainty of the environmental economy and management in the EAEU for the period until 2024. It is recommended that their efforts be focused on the development of responsible production and consumption.

The results of this research will contribute to the ongoing discussions on the topics of environmental monitoring of the energy sphere, as well as management of sustainable and environmental development of the energy economy. This paper revealed the essence and demonstrated the capabilities and advantages of the high-tech approach to this monitoring and management. The limitation of the results obtained during this study is that they identified only scientific and methodological recommendations that should be supported by applied developments for practical implementation, in particular, datasets, the promising frameworks of which are offered by the Institute of Scientific Communications (2022) and UNDP (2022). It is proposed to devote future research to the creation of new datasets with up-to-date data for 2022 and later periods for mass use of the authors' recommendations.

Author contributions

Writing, original draft, writing, review and editing—VY, SL, VG, and AF.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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