sustainability

Article

Towards 2050: Evaluating the Role of Energy Transformation for Sustainable Energy Growth in Serbia

Nemanja Backović, Bojan Ilić, Jelena Andreja Radaković *, Dušan Mitrović, Nemanja Milenković, Marko Ćirović, Zoran Rakićević and Nataša Petrović *

Faculty of Organizational Sciences, University of Belgrade, 11000 Belgrade, Serbia;
nemanja.backovic@fon.bg.ac.rs (N.B.); bojan.ilic@fon.bg.ac.rs (B.I.); dusan.mitrovic@fon.bg.ac.rs (D.M.);
nemanja.milenkovic@fon.bg.ac.rs (N.M.); marko.cirovic@fon.bg.ac.rs (M.Ć.); zoran.rakicevic@fon.bg.ac.rs (Z.R.)
* Correspondence: jelenaandreja.radakovic@fon.bg.ac.rs (J.A.R.); natasa.petrovic@fon.bg.ac.rs (N.P.)

Abstract: This paper aims to investigate the outlook of energy generation by means of transformation within the context of sustainable energy development. An analysis is conducted to assess the stability of energy systems so to implement cutting-edge energy production models at the national level, with a focus on a contemporary approach to energy modeling. Considering the energy transition and the existing constraints within the energy industry, the model assesses the feasibility of the practical advancement of renewable energy sources. The bottom-up energy model was used to determine how the components of energy development sustainability can be applied until the year 2050. To perform comparison testing with the reference state scenario, the LEAP energy model was used. This instrument was selected because of its ability to provide flexible and advanced options for selecting suitable parameters for energy transformation prediction. A progressive reduction in environmental pollution can be achieved by the deployment of current methods of energy generation by transformation until the year 2050 in Serbia, as indicated by the findings. The research highlights the significance of utilizing green energy sources for the continuing development of energy and the gradual reduction in environmental pollution through value co-creation.

Keywords: energy economics; energy transformation; energy efficiency; bottom-up modeling; LEAP modeling tool

check for updates

Citation: Backović, N.; Ilić, B.; Radaković, J.A.; Mitrović, D.; Milenković, N.; Ćirović, M.; Rakićević, Z.; Petrović, N. Towards 2050: Evaluating the Role of Energy Transformation for Sustainable Energy Growth in Serbia. *Sustainability* **2024**, *16*, 7204. https://doi.org/10.3390/su16167204

Academic Editor: Brantley T. Liddle

Received: 15 July 2024
Revised: 13 August 2024
Accepted: 20 August 2024
Published: 22 August 2024

Copyright: © 2024 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

The 1980s saw the end of the first and second global crises in the oil derivatives market, which changed the terms of production and trade in energy products with a focus on market-oriented reforms. This made energy efficiency an especially important topic of study for economists. The conversion of primary energy into secondary energy and the subsequent generation of economically viable tertiary energy is accompanied by the multiplier effect of meeting the energy needs of end-users. This leads to a rational decrease in the proportion of energy-intensive products in the gross domestic product and a shift in emphasis towards the service industry. The constant reduction in energy supply technology costs has led to increased efficiency in terms of reducing the amount of energy utilized per unit of product or service given [1].

It is also possible to view the quantification of energy efficiency in the context of changes in energy intensity on a global scale. As isolated indicators, productivity and energy intensity can overestimate the cause of progress in the field of efficiency. This is due to the fact that efficiency is directly dependent on climate conditions, the growth of the total population, and structural changes in the economy [2]. Productivity and energy intensity are important measures of the advancement of energy efficiency. Productivity is a measure of how efficiently resources, especially energy, are used to generate goods and services. Energy intensity, on the other hand, measures the quantity of energy required to generate one unit of economic output. A drop in energy intensity and an increase in productivity usually reflect a gain in energy efficiency, since more output is produced with less energy. The feedback effect within the framework of microeconomic analysis occurs when end-users try to use more energy services due to the drop in the costs of those services. This would consequently mean that the final energy consumption and energy intensity will decrease more slowly because of the growth in energy efficiency [3].

The areas of emerging research aimed at enhancing energy efficiency can be categorized as follows [4]:

1. Quantifying the decrease in emissions of hazardous gases to determine the diversity of fuel options.
2. Assessing the quality of energy services.
3. Improving the measurement and assessment of the increase in efficiency resulting from energy policy laws.
4. Strengthening the empirical foundation of transaction costs, discounts, and feedback effects in order to bring them in line with regulatory policy.
5. Enhancing the understanding of customer preferences and promoting the use of effective technologies through the strengthening of a research identity that encompasses multiple disciplines.

The arguments supporting energy efficiency regulation can be condensed into the following four crucial and interrelated factors: (1) cost savings for the government, (2) decreased reliance on energy sources, (3) the alleviation of the impacts of greenhouse gas emissions, and (4) the promotion of sustainable economic growth [5]. The rapid rise of the global population and the increasing energy demands of developing nations will undoubtedly hinder efforts to achieve greater energy efficiency. Therefore, it is predicted that, during the next several decades, global prosperity will need to be achieved at a rate twice as fast as the current rate, while using just half of the energy and natural resources currently being utilized [6].

The worldwide shift towards alternative energy sources, driven by the urgent necessity to address the carbon emissions issue, climate change, and to provide energy stability, presents substantial prospects for producing effective renewable energy [7,8]. It is projected that renewable energy sources will overtake fossil fuels by 2050 [9]. During that period, renewable energy sources will account for more than half of global energy production [8–10]. Also, "the focus on renewable energy utilization is growing sharper, due to its sustainability and contribution to greenhouse gas emissions reduction" [11]. The objective of this transition is to replace fossil fuels with renewable energy sources while enhancing the sustainability and responsiveness of the power system. The core principle of generating shared value is pivotal in this process, highlighting the cooperation of many stakeholders.

Additionally, it must be noted that a key idea for accelerating the transition to green energy is co-creation [12]. Co-creation in renewable energy projects enables stakeholders to collaborate and leverage their collective knowledge, resources, and creativity to enhance project outcomes and community benefits [13,14]. The global transition towards alternative energy sources, motivated by the pressing need to tackle climate change and provide energy security, offers significant opportunities to generate efficient renewable energy. The essence of this transformation is in the concept of creating shared value, which emphasizes the necessity of collaboration among many stakeholders, such as governments, companies, and local communities, in order to collectively achieve sustainable development and its goals.

Energy models provide guidance for making investment decisions in expanding the electricity generation capacity. They accomplish this by outlining several ways to satisfy future energy needs while also achieving environmental protection objectives [15]. The authors Heuberger and others [15] also argue that energy models may provide a clear economic rationale for technology in the power system and identify the most favorable investment location. Modeling current energy systems has significant difficulty in including the extensive unpredictability and complexity of the energy system, while also accounting for all of the utilized technologies. Hence, this article presents an analysis of the effects of energy production development via transformation on the sustainable development of energy and the overall stability of energy systems in Serbia.

The overall number of energy models and their complexity are continually increasing as a result of the improved capabilities offered by computers and computer programming. The models vary significantly in terms of their structure and the range of their application, while the complexity of the data acquired sometimes poses a difficult challenge for analysts in the stated subject. The significance of energy models is also evident in the execution of energy decarbonization initiatives. Currently, there is no mention in the scientific literature of the utilization of sophisticated energy models for forecasting energy growth in Serbia. This work aims to address a specific gap in the existing scientific research at the national level. The gap pertains to the analysis of the burden of the energy sector in relation to incentive purchase prices for preferential producers in the field of renewable energy sources (RESs). In addition, the potential effects of the energy transformation on the overall stability of energy systems are examined, offering stakeholders valuable insights into potential advancements and financial opportunities for the adoption of contemporary energy technology.

2. Energy Models

The presence of two separate methods for energy modeling frequently results in contradictions within research and uncertainty among analysts when selecting an appropriate methodology. The lack of adequate information provided by energy firms is considered a constraining element when examining energy in a situation of market failure. Energy models are categorized into top-down and bottom-up approaches based on the analytical method. This fundamental categorization became especially significant in the 1980s and 1990s as a result of the growth of the discourse surrounding the energy efficiency gap.

The bottom-up model's assumptions are determined in relation to the spread of technology, investments, and the operational expenses of power plants [16]. Given their ability to explain the causes of specific outcomes in the energy sector and their reliance on intricate programming, these models can accurately forecast the adoption of new energy production technologies. Their purpose is to provide information on novel support mechanisms for regulatory energy policy [17]. The notion of economic equilibrium can adequately depict the end result of incorporating new production technologies into the energy system. It demonstrates how the system settles into a balanced state when the new technologies are implemented. However, this notion has the following limitation: it does not account for the dynamic, step-by-step process that led to the adoption of these technologies. In other words, while economic equilibrium can depict the final result, it cannot explain the intricacies and changes that occurred along the transition.

Bottom-up models analyze energy efficiency by comparing the energy consumption of a specific technology or device to a reference scenario with the goal of reducing energy use. Compared to the top-down strategy of estimating energy demand, performing ex post research on household income elasticity by incorporating economic and structural variables greatly aids in predicting the amount of energy used per unit of activity [18].

The top-down approach refers to process-oriented models [19]. Top-down energy models, in contrast to bottom-up models, utilize aggregated data to perform synergy analysis across sectors [20]. The models mentioned encompass an examination of the entire economy, taking into account ongoing market distortions, financial spillovers, and income consequences for various economic entities. These models also consider the significant endogeneity of economic activity during the energy crisis period [21]. This means that economic activity is influenced by both external factors such as energy prices and internal elements within the economy. Additionally, the indicated models have various drawbacks. If the data collection is not conducted appropriately, the model may yield a poor level of accuracy. Furthermore, when the top-down approach yields outcomes that diverge considerably from the anticipated results, it indicates that the process, technology, or equipment responsible for the variation cannot be identified [22].

Recently, there have been efforts to develop models that can utilize both analytical techniques to energy modeling. These models aim to integrate a macroeconomic model, which takes a broad perspective, with at least one component of a bottom-up model that focuses on the ultimate energy consumption sector. Hybrid scenarios necessitate the incorporation of both qualitative and quantitative information to effectively combine the distinct fields of engineering, natural sciences, and social sciences. These disciplines often possess contrasting ontologies, epistemologies, and methodologies [23]. However, after extensively examining the available literature, the authors determined that, for a particular aspect of energy development research, choosing a bottom-up model would be the most appropriate approach. This is primarily due to the model's flexibility in adjusting the load parameters of energy systems and its impact on the stability and growth of the energy sector.

Bottom-up models are frequently employed to evaluate the financial viability of energy systems in a broader perspective, strategies for mitigating the release of noxious gases, and, overall, for implementing significant system transformations [24]. The bottom-up modeling technique effectively predicts the behavior of the annual energy efficiency supply function, allowing for the analysis of how energy efficiency responds to unforeseen fluctuations in energy demand [16].

With the limited and seasonal use of renewable energy sources and the deregulation of the electricity market, energy models need to incorporate factors such as seasonal demand fluctuations, price changes, weather predictions, and other variables. This is performed to enhance the competitiveness of energy companies [24]. Due to the gradual nature of technological advancements, the bottom-up method is prone to overestimating the economic benefits of fully implementing energy-saving technologies. Grubb and others [25] have found that bottom-up investigations of practical application indicate a higher potential for reducing emissions of hazardous gases and total costs compared to the top-down model's extrapolation of energy consumption.

Certain bottom-up models incorporate macroeconomic feedback, whilst others calculate microeconomic behavioral characteristics for the selection of energy production technology [26]. According to the same authors, specific top-down models have included technical complexity in the energy supply sectors. Some instances exist where the parameters of endogenous technological change are defined in order to link energy productivity with energy policy that encourages research and development in the area of reducing greenhouse gas intensity [27]. When comparing the deterministic and stochastic models in the TIMES energy model, it becomes evident that the stochastic interpretation is more accurate in estimating the overall costs of the energy system. This is because it considers uncertain parameters that are specific to the model itself [28].

The models given are depictions of the partial equilibrium of the energy sector. They incorporate numerous discrete energy technologies to replace outdated primary and secondary energy processes with the goal of enhancing energy efficiency [21]. Within this framework, Koopmans and Te Velde [29] identify the following three primary domains for research in bottom-up database management:

1. Forecasting the demand for energy and energy services, considering the shift from conventional fuel-based technology to electricity-based technology.
2. The level of energy efficiency is contingent upon the chosen energy development strategy, which can involve either investing in current technology or completely replacing them with more advanced ones.
3. The model may not accurately assess the rate at which the current energy system can adjust to achieve optimal efficiency after the fact. This aspect should be enhanced in future versions of the model.

At the same time, power grid systems worldwide are confronted with several issues, such as escalating demand, the rising use of renewable energy sources, and mounting infrastructural pressure. When faced with this problem, multi-stakeholder participation plays a crucial role in establishing appropriate incentives and facilitating intelligent electricity consumption. Successful collaboration between various stakeholders, including residents, is crucial for the generation of value in sustainable energy. This collaboration aims to maximize the efficient use of smart power usage. In the energy sector, effective methods of co-creating value require utilizing both resource advantages and strategic network positions to actively involve residents. Collaboratively developing intelligent electricity services is essential for maintaining equilibrium in power system demand and encouraging the adoption of sustainable energy consumption [30].

3. Energy Modeling Tool Used for the Empirical Research

The Low Emissions Analysis Platform (LEAP) is a comprehensive tool used for modeling energy processes using the scenario method approach [31], as well as a tool for creating and evaluating "alternative scenarios by comparing their energy requirements, social costs, benefits, and environmental impacts" [32,33]. It is classified as an Integrated Assessment Model (IAM), which is a type of model that analyzes the relationship between energy and climate change. Developed by the Stockholm Environment Institute, this tool is utilized by numerous organizations in over 190 countries worldwide. The LEAP software 2020.1.0.64 model is primarily used in developing countries to facilitate the integrated resource planning of the energy system. Its main objectives include evaluating the reduction in harmful gas emissions from energy sources and devising sustainable strategies for the utilization of renewable energy sources. LEAP's ability to model environmental, economic, and social impacts helps stakeholders understand the potential benefits and trade-offs, making it essential for informed decision making in energy transformation projects.

Another indication of the complexity of the modeling based on an integrated assessment is the fact that multidisciplinary analysis of energy is so advanced in today's world that it frequently requires several hours of labor for the instrument to calculate all of the scenarios that are provided. Integrated assessment models, in the context of game theory, employ a sophisticated mathematical technique to address inquiries regarding the environmental consequences of the energy sector [34].

LEAP supports bottom-up process modeling for energy demand, as well as enabling a top-down approach from a macroeconomic analysis standpoint [31]. When considering the extension of the current energy capacity, this model allows for the utilization of a wider range of accounting and simulation techniques, as well as the optimization of the energy system. The analyst constructing the model has the freedom to choose the methodology, which supports the iterative analytical approach. LEAP does not provide specific guidelines for the data needed to interpret the results. Instead, the analyst assesses the model's complexity and calculates the necessary volume of data. This emphasizes the significance of using an intuitive approach to analyze complicated energy systems and visually represent the underlying structure of the model.

LEAP evaluates alternate scenarios and their effects on the energy sector's self-sufficiency and the country's ecosystem. It can also be used to study possible energy, environmental, and cost effects of various energy usage under rapid economic growth and successful energy policy implementation. The defined scenarios are analyzed by assessing the model's energy requirements, key assumptions, energy production costs, energy sector environmental impact, and economic aspects of sustainable energy system management.

The following four fundamental methods for setting parameters for energy generation through transformation are described in LEAP [35]:

- Disregard the capacity constraints, which is useful for users without power plant capacity information or who do not consider it significant for calculations.
- The user can choose which manufacturing capacity to include and when. This method enables the independent input of external capacitances for various manufacturing technologies.
- The user chooses the production capacity to incorporate, while LEAP sets the implementation time intervals. This technique gives the user full control over resource additions, including power plant operation length and cost. The key difference is

the ability to use endogenous technologies in case of shortages from planned energy transformation capacities.

- In the fourth approach, LEAP decides which production capacities to include and at what intervals. This gives it full control over the allocation of resources for energy production through transformation.

An integral component of the LEAP instrument is the assessment of the process efficiency of power plants, which is crucial for evaluating the impact of a specific energy source on energy production through transformation. This assessment was conducted using data provided by the Ministry of Mining and Energy of Serbia [36]. The utilization of process efficiency by LEAP is illustrated in Figure 1 below.

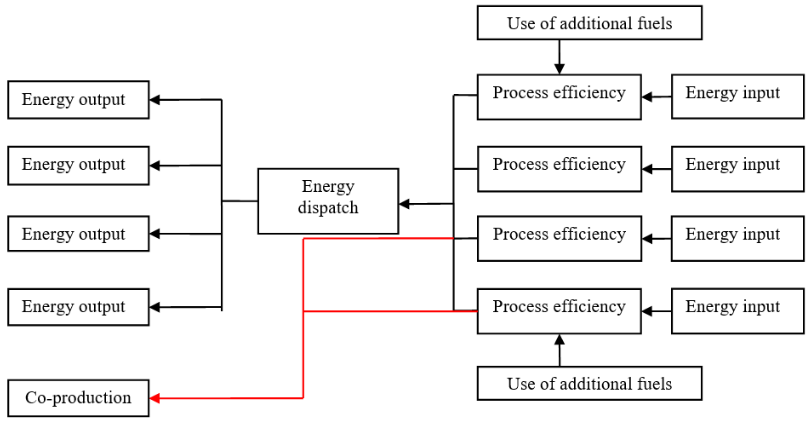

Figure 1. Standard process of energy production by transformation in the LEAP model. Source: Heaps [32].

Extensive model testing is necessary to analyze energy production through transformation and accurately estimate the future development of the energy sector. This category allows users to input comprehensive data regarding the projected movement of overall expenses for power plants, including capital costs, variable costs, historical costs, remaining loan repayments, and various other interconnected economic variables. These capacities are expected to enhance the direction of energy exports and promote a shift towards increased investments in the energy sector [37]. The impact on the technological advancement of the nation is clearly seen via the rejuvenation of current production systems and the implementation of contemporary energy systems, such as the co-generation program (CHP—Combined Heat and Power). This significantly decreased the burden of energy imports.

The LEAP system determines which production capacities to add and when they will be added. Within the fourth approach, LEAP has complete control over the allocation of available resources for energy production through transformation. This allocation is initially determined by the system's cost optimization methodology. The optimization can only be applied to one of the predefined situations, allowing for a comparison with another scenario that the user can still manipulate in their modeling process. The provided flexibility simplifies the decision-making process regarding the prioritization of alternative energy sources. Regarding data availability, the primary emphasis lies in the construction costs, maintenance costs, energy costs, and operational costs of power plants.

Certain additional advanced bottom-up optimization models, such the MARKAL (Market and Allocation) model, rely on the idea that energy consumers would typically choose the best course of action. The challenge in modeling arises from customers frequently making the wrong assumptions due to unreliable information and illogical decision making, hence hindering the creation of a realistic model [38]. The disparity between the MARKAL and LEAP models is notably substantial when evaluating these advanced features. While acknowledging the significance of the MARKAL model, it was concluded that LEAP would be the most appropriate choice for implementing the model in this research.

In order to generate scenarios in this research, multiple tests were conducted to explore various ways of combining factors with the aim of optimizing the entire system. Factors such as the prevailing technological trends, the state's economic capacity to adopt new technologies, and macroeconomic projections until 2050 were considered. Modeling the integration of renewable energy sources into the energy system while considering the existing limits is particularly difficult. The model ruled out the prospect of achieving a scenario where renewable energy completely replaces conventional energy sources by 2050, concluding that this process is impossible to achieve within a reasonably short timeframe.

The analysis of fiscal risks and issues faced by public firms in the energy sector of Serbia, as well as delays in the construction of new energy facilities and deficiencies in the Electric Power Industry of Serbia distribution network, are receiving significant attention.

After setting the parameters within the framework of energy production by transformation, the optimal solution for creating alternative scenarios was reached. This was accomplished by referring to the following: (1) the energy dispatch rule, (2) the process efficiencies of power plants, (3) the percentage participation of power plants, and (4) the maximum availability capacity.

The energy dispatch rule is a crucial element in the modeling of energy operations in LEAP. The instrument itself allows for the specification of how unmet requirements will be addressed. The current energy situation in Serbia has led to the establishment of distinct criteria for the scenario of the moderate use of renewable energy sources, SCOIE1, and the scenario of intensive use of renewable energy sources, SCOIE2, which are presented in the accompanying figures for the purpose of this research. In the reference scenario (REF), the criterion "Meet with Imports" was approved due to the consistent trajectory of energy development, which remains unaltered compared to the present situation (Figures 2 and 3).

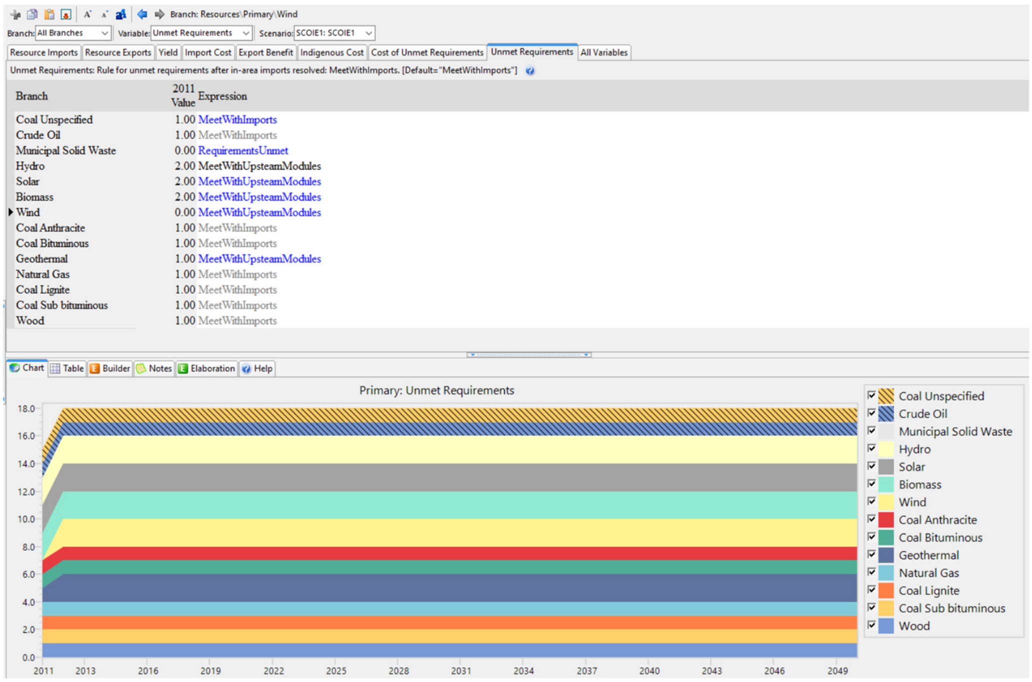

Figure 2. A summary of functions for meeting energy requirements in the LEAP model—SCOIE1 scenario. Source: the authors' analysis, based on [31].

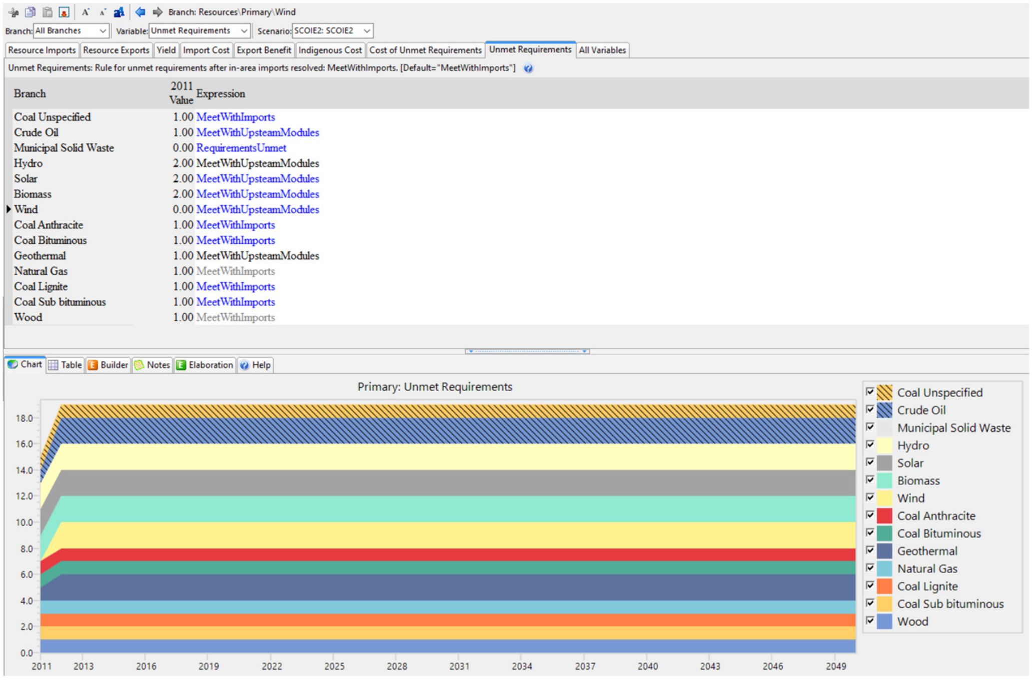

Figure 3. A summary of functions for meeting energy requirements in the LEAP model—SCOIE2 scenario. Source: the authors' analysis, based on [31].

The decision to use the LEAP instrument for modeling and optimizing the growth of the energy sector in Serbia was justified, as it successfully incorporated both macroeconomic and microeconomic analyses. The specified software tool allowed for the input of all crucial assumptions, as well as the endogenous and exogenous variables of the model. LEAP was chosen for the research because it can be applied to various levels of the energy system. It is particularly useful for assessing how energy production affects the overall costs of the energy sector based on the current prices for purchasing electricity from preferential producers. The support mechanisms for renewable energy sources, namely, the incentive purchase price, play a crucial role in establishing the model, defining restrictions, and specifying the assumptions for the efficient operation process of power plants, particularly in the context of Serbia. In order to generate the three different scenarios, the authors of this paper input data on the total amount of incentive purchase prices, using the official data provided by the Government of the Republic of Serbia [36,39]. The model will be discussed from the perspectives of rationalizing electricity consumption, analyzing the costs and benefits of using new energy production technologies, examining the relationship between economic growth and the sustainable operation of business entities, the active participants in the electricity market, and assessing the model's influence on the operations of specific stakeholders in the energy sector group.

The socio-technical system has a significant impact on the formation, maintenance, and stabilization of the energy demand, even if it is based on economic decisions and consumer preferences [40]. The constraints could also act as an obstacle to the adoption of next-generation technology. Not only would this increased cooperation among companies maximize the deployment of renewable energy sources as a strategy, but it would also lessen the knowledge imbalance between power generators and consumers. Moreover, the likelihood of encountering unmet energy needs in the specified model parameters would be diminished.

4. Empirical Data and Scenario Analysis

To investigate the development of the Serbia's energy system until 2050, three alternative scenarios have been established: the REF scenario, the SCOIE1 scenario, and the SCOIE2 scenario, as follows:

1. The REF scenario was developed as a research model and is an altered version of the state reference scenario of Serbia, as outlined in the "Energy Development Strategy of Serbia until 2025, with forecasts until 2030" by the Ministry of Mining and Energy of Serbia in 2015 [36]. The reference scenario examines the feasibility of improving the nation's power system without introducing new energy policy measures, additional reductions in energy use, or actions to improve energy efficiency. The reference scenario includes measures that can enable a coordinated approach to setting regulated circumstances for the energy market. However, it mainly excludes innovative combinations of regulatory policies that would change the existing path of the country's development of energy.
2. The SCOIE1 scenario was developed independently to forecast the future development of the energy sector in Serbia until 2050. The scenario includes data up to 2020, which is the latest year for which conclusive data on the energy industry are provided. The LEAP model enabled the advanced modeling of a comprehensive scenario, incorporating both the macroeconomic and microeconomic analyses of future events. The purpose of constructing the SCOIE1 scenario was to examine the incorporation of renewable energy sources (RESs) into the energy system of Serbia. This analysis will also consider the possible obstacles, limitations, and challenges involved with this approach.
3. The SCOIE2 scenario is the last of the three different scenarios that were created for this research. The SCOIE2 scenario integrates data from the SCOIE1 scenario and then modifies them to align with the particular criteria of the study. The SCOIE2 scenario is a projection of Serbia's energy sector development until 2050. The analysis explores the feasibility of integrating renewable energy sources to the maximum extent feasible, taking into account the constraints of the existing energy system.

In order to construct the energy development model of Serbia from 2011 to 2050, an extensive quantity of data were gathered from the official sources of both national and international entities. The year 2011 serves as a reference year, whereas 2012 is the initial year for which results are computed for different scenarios. To effectively evaluate the model, historical data from 2012 to 2019 were used for annual comparison. The validation of the model for energy production through transformation from 2012 to 2019 has also proven that the model satisfies the criteria for the long-term forecasting of the energy industry. The year 2011 was selected as the initial year for inputting data into the model, as it coincided with the most recent census of the population, households, and apartments in Serbia. Subsequently, 2012 was designated as the starting year for the scenario. The model's reliability was tested and any discrepancies during projection were minimized by using the period span until the final published energy balance from 2023. The data presented are sourced exclusively from the official energy balance reports published by the Statistical Office of the Republic of Serbia. Model validation and the comparison of historical data with the modeled data are shown in Table 1.

The disparities between the official historical data and the data generated by the produced model can be attributed to the utilization of a bottom-up modeling technique. If the model is not properly configured, there is a high probability that the distribution of the input data and the amounts of energy produced in each observed year would be disrupted. By redistributing or reallocating the generated energy to other subcategories, namely, to power plants that have not fulfilled the energy demands, it is possible to achieve outcomes that may mislead analysts regarding the trajectory of energy system development. Model validation is conducted to determine if there were any disruptions in the model that might subsequently impact future years. The selection of energy sources in Serbia was based on crucial groupings that have the highest contribution to electricity production.

Table 1. Model validation—comparison of historical data with the model data (in TJ).

Year	2012	2013	2014	2015	2016	2017	2018	2019
Type of powerplant								
Thermal powerplant official	94,590	103,032	79,463	97,678	98,392	96,140	89,911	91,966
Thermal powerplant model	94,579.8	103,005.2	79,465.5	97,678	98,389.8	96,128.9	89,890.6	91,942.1
Deviation	−0.0001%	−0.0002%	0.00003%	0%	−0.00002%	−0.0001%	−0.0002%	−0.0002%
Coal official	9134	9134	4801	5852	7708	9035	7508	6439
Coal model	9127.2	9127.2	4814.8	5861.5	7703.7	9043.5	7494.4	6447.7
Deviation	−0.0007%	−0.0007%	0.0028%	0.0016%	−0.0005%	0.0009%	−0.0018%	0.0013%
Oil refinery official	96,917	131,242	134,837	145,700	150,925	159,153	168,902	154,319
Oil refinery model	96,924.4	131,256.2	134,835.9	145,700.6	150,934.1	159,140.3	168,895.5	154,325.4
Deviation	0.00007%	0.00010%	−0.000008%	0.000004%	0.00006%	−0.00007%	−0.00003%	0.00004%
Wood pellet official	1448	2011	2814	1809	2224	4294	4267	4427
Wood pellet model	1444.4	2009.7	2805.2	1800.3	2223.6	4291.5	4270.5	4438
Deviation	−0.0024%	−0.0006%	−0.0031%	−0.0048%	−0.0001%	−0.0005%	0.0008%	0.0024%
Wood chips official	238	311	329	152	371	326	302	254
Wood chips model	251.2	314	334.9	150.7	371	334.9	293.1	251.2
Deviation	0.0525%	0.0095%	0.0176%	−0.0085%	0%	0.0265%	−0.0294%	−0.0110%

Source: authors' analysis.

During the testing of the model for energy production, a discrepancy was noticed compared to the official data from the energy balances of Serbia for the period spanning from 2012 to 2019. The variance ranged from −0.0310% to 0.0229%. Therefore, it can be concluded that the model is reliable and fulfills the requirements for generating plausible alternative scenarios for the long-term energy sector. Between 2020 and 2024, consistent slight deviations were observed for the specified model, providing confirmation that reliable research utilizing the scenario technique with the LEAP instrument can be conducted.

5. Results and Discussion

The strong correlation between the official and modeled data demonstrates the LEAP model's ability to accurately replicate Serbia's energy system. Precision in this matter is essential for stakeholders to make well-informed decisions on energy policies, investments, and strategies, thus improving the process of value co-creation. The analysis could clarify the possible advantages and obstacles of different energy transformation trajectories by contrasting the reference scenario (REF) with the moderate (SCOIE1) and intensive (SCOIE2) renewable energy scenarios. This allows for the identification of the most sustainable and successful strategies, promoting collaboration among stakeholders. By involving various stakeholders in the modeling process, the study encourages a common comprehension and collaborative effort towards the advancement of sustainable energy. The data-driven method enables an extensive assessment of the environmental, economic, and social consequences of various energy scenarios. A clear comprehension of this matter is crucial for co-creating values that blend diverse interests and fosters sustainability.

The production of energy through transformation was selected as the research area, since it aims to promote the rational use of energy and the improvement of energy efficiency, as well as the promotion of positive climate changes in the field of energy and the improvement of the coordination of the activities of all energy companies.

The energy production projection through transformation inside of the LEAP model is intricate due to the various parameters involved and the complexity of the modeling process assumptions. Because scenario generation is performed in a bottom-up manner, it is best to enter all available information about power plants' exogenous and endogenous capacities, together with the rules governing the order in which different energy kinds should be sent. The placement of the transformation categories is crucial, as it might lead to significantly varied and contradictory outcomes if not performed correctly. The computation methodology begins by assessing the potential losses during the energy transmission and distribution, followed by evaluating the electricity output through transformation. This allows the model to compute losses using a bottom-up approach and evaluate the necessity of utilizing the input power plant capacity.

To ensure an accurate representation of the current energy system and provide a realistic projection of future energy sector development, the model defines energy production by transformation based on historical production data from the year prior to the scenario's base year, specifically, 2010 (referred to as Historical Production in the model parameter). The transformation module in LEAP allows for calculations based on feedback on the energy flow, facilitating the adaptation to more intricate energy systems [31]. Hence, the model can accurately compute the allocation of energy produced by the power plant for its own consumption. By making iterative adjustments to the system, we can fulfill the unmet energy needs that arise from energy flows coming from upstream sources.

The model has employed the energy dispatch rule for simulation since 2011. Consequently, the significance of establishing these rules is explained in a distinct portion of the text. In the SCOIE2 scenario, the choice was made to input the percentage of participation for each type of power plant. According to this scenario, thermal power plants are not allowed to have a participation rate higher than 60.5%, specifically 58.2%, for the years 2025 and 2050 in terms of electricity production through transformation.

The model calculates the maximum level of involvement of thermal power plants by considering the projected lifespan and process efficiency of these plants. This measure was implemented to incentivize the generation of energy from sources that emit lower levels of greenhouse gases (GHGs).

After conducting 143 tests with various parameter settings, the most effective approach for generating four alternative scenarios in energy production through transformation was determined. These tests considered factors such as the rule of dispatching energy, process efficiencies of power plants, the percentage participation of power plants, the maximum capacity availability, and the merit order effect.

The results for the projection of the energy production through transformation for four different scenarios were produced using the aforementioned model. To enhance the clarity of the results, the model emphasizes the future projections that are relevant. These projections focus on the period starting from the year 2025 and extend beyond, covering a five-year timeframe. This period is crucial, as it is predicted to witness substantial strategic shifts in the energy sector.

The assumption made is that there will be no change in energy production from the transformation of coal types for the REF scenario up until 2030, which is the last year of the projection from the report on the energy strategy of Serbia. When the framework of the calculation procedure conducted by LEAP was taken into consideration, the offered assumption demonstrated the best outcomes through the model testing. Therefore, the focus in both of the above situations was on correcting the movements of the other types of transformations with the goal of ensuring the accuracy of the total projection. Further modifications in the specified subcategory would complicate the calculation process and hinder an accurate depiction of the energy conversion, hence disrupting the forecast of coal-based primary energy generation.

For the other types of energy conversion, there is a forecast of slightly slower growth in production compared to the data until 2030. An example of this is energy production through the conversion of oil and oil derivatives, where a slower increase of 0.08% is expected. This prediction considers new trends in the energy sector and the delay in implementing energy strategies. Furthermore, the reference scenario suggests that there will be a rise in the value of accessible power because of conversion, with the prevalence of environmentally harmful fuels still prevailing, which affects the overall economic stability [41]. The model demonstrates that the official data entered regarding planned capital investments in the energy sector may potentially improve the relatively low operational efficiency of thermal power plants and combined heat and power facilities, which typically have a maximum availability rate of over 80%.

As shown in Table 2, an issue that could hinder the long-term sustainability of the energy system in the REF scenario is the high electrical consumption needed for the continuous operation of thermal power plants. This consumption is accounted for in the model under the self-consumption section of the energy sector. It is important to remember that approximately 92% of coal consumption is used as a fuel input for energy conversion in thermal power plants [36]. Furthermore, alternative fuels utilized in the conversion process within thermal power plants, such as sub-bituminous coal, exhibit a significant release of greenhouse gases. The subsequent section takes into account all emissions and inputs them into the LEAP model. In the REF scenario, the increase in thermal energy output through transformation is expected to put extra strain on the energy sector's import side, as natural gas is the primary fuel used for this process. The potential danger associated with the use of fossil fuels is also considered in the LEAP model, where the presence of toxic compounds is measured to determine the total energy efficiency of the system [42].

Table 2. Energy production by transformation in the REF scenario (in 1000 million tons of oil equivalent—mtoe).

Year	Oil and Oil Derivatives	Heat	Electricity	Coal
2050	5270.1	1428.2	4111.2	474.0
2049	5201.2	1408.0	4072.9	474.0
2048	5132.3	1387.9	4034.7	474.0
2047	5063.5	1366.9	3996.6	474.0
2046	4994.6	1345.7	3958.5	474.0
2045	4925.7	1324.6	3920.5	474.0
2044	4861.4	1303.9	3886.1	474.0
2043	4797.1	1283.2	3851.8	474.0
2042	4732.8	1262.5	3817.5	474.0
2041	4668.5	1241.8	3783.3	474.0
2040	4604.1	1221.1	3749.1	474.0
2039	4544.0	1203.4	3714.1	474.0
2038	4483.8	1185.6	3679.2	474.0
2037	4423.7	1167.2	3644.3	474.0
2036	4363.5	1148.8	3609.4	474.0
2035	4303.3	1130.5	3573.6	474.0
2034	4255.6	1119.9	3542.0	474.0
2033	4207.9	1109.3	3510.4	474.0
2032	4160.3	1098.7	3478.7	474.0
2031	4112.6	1088.1	3446.9	474.0
2030	4064.9	1077.6	3415.1	474.0
2029	4010.9	1057.5	3373.3	474.0
2028	3956.9	1037.5	3331.2	474.0
2027	3902.9	1017.5	3289.0	474.0
2026	3848.9	997.6	3246.5	474.0
2025	3794.9	977.7	3203.9	474.0

Source: authors' analysis.

Due to the multidisciplinary nature of energy production through transformation, it is difficult to conduct analyses and projections on this process, particularly regarding the establishment of a reliable energy supply and distribution system. The SCOIE1 scenario depicts a progressive decline in the system's reliance on oil derivatives, as seen in Table 3. The disparity between this scenario and the REF scenario grows from 372.3 thousand tons of oil equivalent in 2025 to 1.155 million tons of oil equivalent in 2050.

It should be noted that the percentage changes are referring to the time period beginning in 2025 and to the ratio of total values that occurred within the time range that was observed. Undoubtedly, the percentage differences would be far larger between these possibilities and the reference scenario if the full simulation was viewed regarding the base year of 2011.

Table 3. Energy production by transformation in the SCOIE1 scenario (in 1000 mtoe).

Year	Wood Fuels	Oil and Oil Derivatives	Heat	Electricity	Coal
2050	51.7	4115.1	1278.8	3394.1	407.7
2049	51.7	4088.6	1261.4	3382.1	406.6
2048	51.7	4062.0	1244.0	3370.1	405.5
2047	51.7	4035.5	1226.7	3358.1	404.4
2046	51.6	4008.9	1209.3	3346.1	403.3
2045	51.6	3982.4	1191.3	3334.0	402.2
2044	51.6	3931.7	1171.8	3322.6	401.1
2043	51.5	3881.0	1152.3	3311.2	400.0
2042	51.5	3830.3	1132.8	3299.8	398.9
2041	51.5	3779.6	1113.3	3288.3	397.8
2040	51.4	3729.0	1092.2	3276.8	396.7
2039	51.4	3695.7	1077.1	3267.8	395.6
2038	51.4	3662.5	1061.9	3258.7	394.6
2037	51.3	3629.2	1046.8	3249.5	393.5
2036	51.3	3595.9	1031.6	3240.4	392.4
2035	51.3	3562.7	1016.5	3231.3	391.3
2034	51.2	3540.3	1007.3	3223.5	390.2
2033	51.2	3517.8	998.1	3215.7	389.1
2032	51.2	3495.4	988.9	3207.9	388.0
2031	51.2	3472.9	979.8	3195.4	386.9
2030	51.1	3450.5	970.6	3180.6	385.8
2029	51.1	3444.9	955.3	3151.7	391.1
2028	51.1	3439.4	940.0	3122.8	396.4
2027	51.0	3433.8	924.8	3093.8	401.7
2026	51.0	3428.2	909.5	3064.8	407.1
2025	51.0	3422.6	894.2	224.3	691.0

Source: authors' analysis.

This presentation covers the time span from 2030 to 2050. The projections indicate a much greater utilization of wood fuels in the SCOIE2 scenario as compared to the SCOIE1 scenario, particularly for the manufacturing of wood pellets and wood briquettes. The primary objective is to create a market for wood and agricultural biomass in order to enhance the competitiveness of producers in this region.

Wood pellets may be effectively used for energy generation, with a capacity utilization rate of above 90% [43]. Transitioning the center of gravity from conventional fuels to renewable energy sources and targeted biofuels is a gradual and ongoing process. Based on the model's results, it is highly unlikely that there would be a total shift towards "clean" energy in the transformation sector by 2050, as shown over the relatively short period of time.

If the installation of renewable energy sources is not precise, it could exacerbate the issue of importing electricity and place a financial burden on the state budget. The Fiscal Council's study reveals that the failure to evaluate fiscal risks and quantify expenses may once again result in using loans to cover costs, as is currently the situation with specific public businesses in the energy sector [44]. The risk also lies in the potential complementarity of energy sources, which might indirectly harm new production facilities by abruptly discontinuing the usage of one source.

The SCOIE2 scenario demonstrates a significant decline in energy production from oil, resulting in a production level of only 2583.6 thousand tons of equivalent oil by the last year of the simulation. The scenario predicts that possible shortages of refined petroleum energy would be offset by the establishment of additional biofuel production plants. Equally significant is the integrated generation of heat and electricity in contemporary CHP (Combined Heat and Power) facilities, which is likewise encompassed in the situation, with the corresponding incentivized purchasing costs. According to the Ministry of Mining and Energy of Serbia [36], the proportion of co-generation plants in Serbia is now quite small. As a result, the modeling of the scenario aims to address and improve these deficiencies.

It is evident that, in the SCOIE1 scenario, the development of electricity output will be slower compared to the REF and SCOIE2 scenarios. Specifically, when comparing the SCOIE1 scenario to the REF scenario, this forecast assumes an energy efficiency increase, resulting in lower end energy consumption and electricity consumption in power plants. Figure 4 provides more information about the disparity in energy production patterns between the REF and SCOIE1 scenarios.

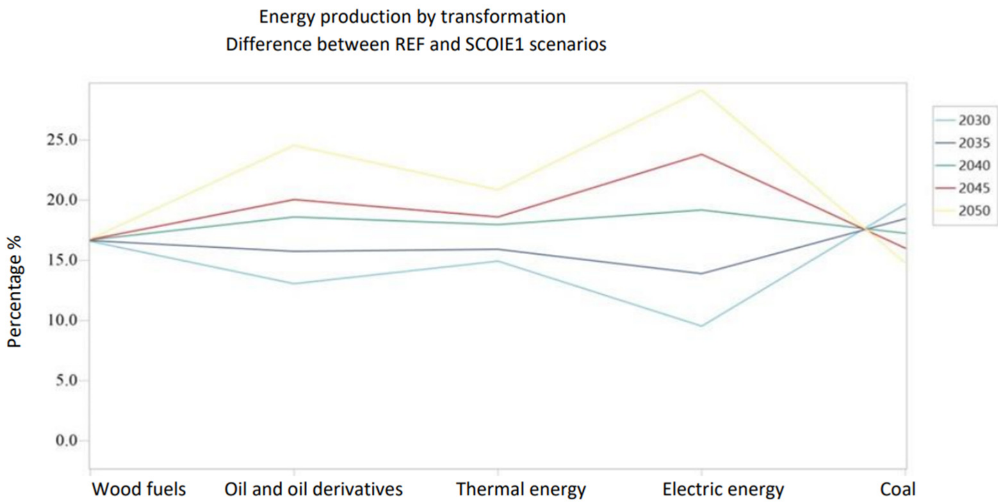

Figure 4. The difference in the dynamics of the energy transformation between the REF and SCOIE1 scenarios. Source: Heaps [31].

Given that the emphasis will be placed on developing new technologies in the field of electricity, the graphic presentation reveals disparities that appear to be substantially bigger than the absolute values that are displayed. This is because the creation of thermal energy through transformation is the subject of the attention. In the SCOIE2 scenario, the modeling incorporates the export-driven element, which means that the demand for energy goods in the domestic market would surpass its needs. According to the SCOIE2 scenario for the year 2050 outlined in Table 4, the anticipated output of heat energy through transformation is expected to be 51,140 TJ (Terajoules). This is lower than the expected 53,541 TJ for the SCOIE1 scenario and 59,796 TJ for the REF scenario. Additionally, it is crucial to investigate the operational effectiveness of power plants in terms of converting energy. Therefore, in the SCOIE2 scenario, there was a reduction of 14,643 TJ in the use of natural gas as a power plant input in comparison to the REF scenario. The model also demonstrates the disparity in using the SCOIE1 scenario, with a decrease of 8806 TJ compared to the REF scenario. In the SCOIE1 and SCOIE2 scenarios, significant reductions in natural gas consumption for heat energy production through transformation are expected in 2036 and 2041, respectively. These savings are estimated to surpass 5000 TJ compared to the REF scenario.

Additionally, the model predicts that, by the year 2050, there will be a decrease in the disparity between the amount of money spent on energy production and the total energy generated through transformation. Specifically, the estimated energy expenditure for the REF scenario is 286,803 TJ, while, for the SCOIE2 scenario, it is 158,999 TJ. The SCOIE2 scenario exhibits a significant level of rapid changes, particularly throughout the time span from 2033 to 2044.

Table 4. Energy production by transformation for the SCOIE2 scenario (in 1000 mtoe).

Year	Wood Fuel	Oil and Oil Derivatives	Heat	Electricity	Coal	Biofuel Production
2050	25.7	2583.6	1221.5	5418.2	258.7	369.4
2049	26.6	2587.6	1208.8	5366.6	258.9	363.3
2048	27.4	2591.6	1196.0	5315.0	259.1	357.3
2047	28.2	2595.6	1183.3	5263.3	259.3	351.3
2046	29.1	2599.6	1170.6	5211.5	259.6	345.3
2045	29.9	2603.6	1157.9	5159.7	259.8	339.5
2044	30.7	2607.6	1140.1	5137.1	258.5	333.6
2043	31.6	2611.6	1122.3	5114.5	257.2	327.9
2042	32.4	2615.6	1104.6	5091.9	255.9	322.1
2041	33.2	2619.6	1086.8	5569.3	254.5	316.5
2040	34.1	2623.6	1069.0	5546.6	253.2	310.8
2039	34.9	2627.6	1052.6	5524.8	251.9	305.3
2038	35.8	2631.6	1036.3	5503.0	250.6	299.7
2037	36.6	2635.6	1019.9	5481.2	249.3	294.3
2036	37.4	2639.6	1003.6	5759.3	248.0	288.8
2035	38.3	2643.6	987.2	5737.3	246.7	283.5
2034	39.1	2649.0	986.0	5703.3	245.3	278.1
2033	39.9	2654.3	984.8	5669.2	244.0	272.9
2032	40.8	2659.7	983.6	5631.3	242.7	267.6
2031	41.6	2665.0	982.4	7541.2	241.4	262.5
2030	42.4	2670.4	981.3	7496.6	240.1	257.4
2029	43.3	2603.4	964.7	7470.4	245.1	252.3
2028	44.1	2536.4	948.2	7444.0	250.1	247.3
2027	45.0	2469.3	931.7	7417.4	255.1	242.3
2026	45.8	2402.3	915.2	7390.5	260.1	237.4
2025	46.6	2335.3	898.7	7363.5	265.1	232.5

Source: authors' analysis.

According to the SCOIE2 scenario, the simulation assumes that creating a favorable investment environment and establishing a stable, long-term relationship between privileged producers and public companies would reduce the amount of thermal energy production, which is a significant source of environmental pollution. Considering the economic contributions of the analysis, it is crucial to note that this category also incurs significant variable costs in energy generation. The primary objective of incorporating the full potential of renewable energy sources in the SCOIE2 scenario is to prioritize the advancement of electricity as a catalyst for economic growth. While time series analyses have not thoroughly investigated the role of electricity in economic development and its cause-and-effect relationship, it is evident that increased energy usage is strongly correlated with a positive trend in GDP [3]. Figure 5 provides a visual depiction of the changes in movement between the REF and SCOIE2 scenarios, highlighting the notable variations that can impact the stability of energy systems.

The risk of system imbalance arises when there is a sudden and poorly planned replacement of available capabilities. This can lead to unexpected power supply interruptions that have the potential to entirely damage the power system. In addition, it should be noted that the proposed increase in energy reserves, as determined by the Energy Agency of the Republic of Serbia [39], would be approximately twice the current level for the SCOIE1 scenario, and up to five times greater for the SCOIE2 scenario. An issue arises about the export of power generated from these sources, specifically the concern of overloading the transmission infrastructure, which negatively impacts end-customers.

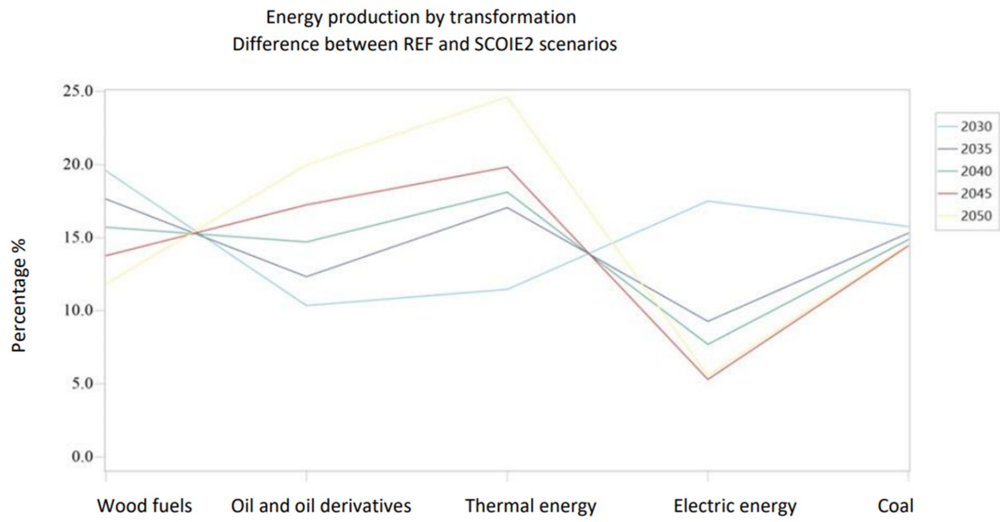

Figure 5. The difference in the dynamics of energy transformation between the REF and SCOIE2 scenarios. Source: Heaps [31].

The obligatory RES reserves criterion is a significant indicator of the strategic link to the transmission system. Put simply, RES producers would assume accountability in the case of a decrease in production and unforeseen interruptions in the functioning of power facilities. Considering that these sources often have poor capacity utilization due to the seasonal nature of the job, the request for energy storage was deemed legitimate during the model's development. Furthermore, the recommendations about the matter of balancing responsibility are acknowledged as vital to the strategic advancement of the energy industry.

The LEAP tool enables the evaluation of the practical achievement of the objectives of privileged energy producers by determining the average annual usage of energy sources. For instance, if a criterion is established stating that a wind power plant can only operate at 25% of its full capacity per year (with variations depending on the season), LEAP will calculate the total capacity of the power plant based on the criterion for the availability of renewable energy sources. Hence, it is crucial to incorporate the internal capacity for energy production through conversion when integrating new technologies so as to facilitate energy generation in situations of unforeseen increases in energy requirements. The model will utilize the inherent capability of the power plants to meet the necessary margin level of the anticipated energy reserves. The electricity generated from renewable energy sources in this scenario constitutes an average of 30% (subject to variation depending on the specific kind of energy).

Increased system load and greater demand for electricity from internal capacity can also occur as a result of increased losses from other upstream modules. Therefore, for instance, higher levels of thermal energy losses would place a heavy load on the reserves of the electrical module. The margin of planned reserves is exclusively determined for the SCOIE2 scenario to assess its potential influence on energy production through transformation in comparison to other scenarios. The assigned values for wind energy, solar energy on buildings, solar energy on the ground, and geothermal energy are 100,000 tons/year, 10,000 tons/year, 30,000 tons/year, and 5000 tons/year, respectively. However, it should be noted that the mentioned figures are not necessarily anticipated to be achieved based on practical forecasts, nor are they projected to be fully utilized for the energy industry's requirements. Conversely, endogenous capacities were implemented to assess the long-term viability of using exogenous capacity in the context of energy transformation with the objective of substituting conventional energy sources. Table 4 provides comprehensive data for the energy transformation forecasts in the SCOIE2 scenario.

From an economic perspective, stabilizing the system and fully utilizing renewable energy sources (RESs) in line with the SCOIE2 scenario's energy requirements would undoubtedly provide significant benefits for the competitiveness of energy entities, for stakeholders, and the overall economic growth. Table 5 presents the predicted cumulative value of the total energy import and export for different sources of energy, including coal, electricity, oil, and oil derivatives, based on the reported price changes from 2012 to 2023.

Table 5. Projection of cumulative benefits from the import and export of energy of Serbia for the period until 2050 (in euros).

Scenario	REF	SCOIE1	SCOIE2
Import	27,385,482,226	26,189,170,246	25,519,658,714
Export	12,821,423,796	15,896,245,419	23,391,927,037

Source: authors' analysis.

While the SCOIE2 scenario shows favorable outcomes in terms of the ratio of energy imports and exports, the main concern is whether the ideal circumstances necessary for promoting renewable energy sources at the national level by 2050 can be realized. Given the specific criteria, it may be inferred that the decision to stop importing crude oil caused significant changes to the SCOIE2 scenario. There is a clear and evident shift towards reducing the dependence on crude oil for energy conversion. This can be demonstrated by contrasting it with the REF scenario, in which the projected energy consumption for the year 2050 is 211,839 TJ, a figure that is considerably greater than the 88,120 TJ derived from the whole capacity of the RES SCOIE2 scenario. Furthermore, there will be a substantial increase in power production until 2031 as long as the maximum availability of these energy sources remains unchanged. Starting in 2032, the model predicts a gradual shift in energy sources because the system is unable to completely replace the use of fossil fuels within a specific period. The problem of not meeting the specified annual requirement of 61,379 TJ of crude oil will not be resolved in the SCOIE2 scenario. According to the findings, Serbia will not be capable of completely replacing the use of fossil fuels with renewable energy sources (RESs) by 2050 due to the constraints in the energy production capacity.

In this instance, it is possible to demonstrate that the REF scenario will result in an extraordinarily significant rise in total expenses, particularly in the area of energy generation through transformation. In the event that privileged energy producers did not shoulder some of the obligation, the strain that is placed on the system would be exponentially increased. With the REF scenario, the potential for the instability of the energy system is demonstrated once more in the context of the occurrence of a total stoppage in the supply of power and a significant negative impact that might develop in terms of environmental protection. This possibility is presented in the framework of the hypothetical situation. It is possible to claim that this scenario poses the biggest threat to the energy security of Serbia when evaluated from the perspective of energy flows at the national level based on these results, which are examined through the framework of the prior results of assessing the cost efficiency of the REF scenario.

The study also analyzed the whole costs of electricity generation through transformation by considering the fixed incentive purchase prices for energy producers in Serbia. The model included the official data from the Energy Agency of the Republic of Serbia to determine the unique incentive purchase prices for RES technologies. By analyzing the data, we can assess the impact of incentive purchase prices on the overall costs of power production in the energy industry. The projection of the cumulative total costs to produce electricity by transformation in Serbia for the period up to 2050 is given in Table 6.

Incorporating both macro- and microeconomic analyses strengthened the findings by providing a more thorough framework for evaluating the efficacy of contemporary technology in this area. Thus, the results show that the SCOIE2 scenario is the most environmentally beneficial, but it is highly unlikely to be achievable given the energy sector's existing limitations.

Table 6. Projection of cumulative total costs to produce electricity by transformation in Serbia for the period up to 2050 (in euros).

Scenario	REF	SCOIE1	SCOIE2
Cumulative total energy transformation costs	60,429,898,300	57,875,858,706	80,698,521,392

Source: authors' analysis.

The findings suggest that the incremental integration of renewable energy sources (RESs) would result in a decrease in overall expenses, even though the loads from the incentive purchase price side would have a greater absolute value owing to the installation of additional production capabilities. Improvements in energy efficiency, such as energy savings, new energy storage systems, reduced electricity losses in distribution and transmission, and the increased process efficiency of power plants, would result in both enhanced energy efficiency and lower overall costs in terms of subsidized electricity sales prices. When comparing the REF scenario to the SCOIE1 scenario, there is a noticeable reduction in expenses of a little more than EUR 2.5 billion.

To further verify the trustworthiness of the empirical data, the case of the SCOIE2 scenario is also examined. The previous research concluded that implementing the SCOIE2 scenario might lead to a decrease in energy security, making it more challenging to take into account the economic considerations of the specified energy mix. In the context of a significant focus on exporting energy, enhancing the time forecasts and flexibility of the energy system could potentially yield more accurate insights into the economic rationale for supporting renewable energy sources within the SCOIE2 scenario. If there were data available on future electricity costs, a thorough study could be performed. The absence of certain components in the specified evaluation indicates that the financial viability of RES investments, as per the SCOIE2 scenario, cannot be verified.

The objective of obtaining these data was to assess the long-term sustainability of energy development and the financial viability of the scenarios offered for stakeholders. An investigation was conducted, among other objectives, to see if the electricity grid could remain stable for the specified timeframe. The collected results provide valuable insights for the future advancement of the energy sector and validate the assertions made by representatives of the public company "Elektromreža Srbije" (National company for energy transmission) about the balance of energy systems.

6. Conclusions

The selection of the LEAP tool for bottom-up energy modeling was found to be suitable for the unique requirements of analyzing relationships within the sector and for providing significant estimates on the future utilization of energy sources. The program's sophistication in the chosen methodological framework allowed for the prediction of the utilization of renewable energy sources in terms of the increase in energy efficiency. The assessment of how the usage of renewable energy sources affects the cost effectiveness of the system further validates the rationale for implementing the recommended energy development strategies. An exposition of the many types of energy models and their comparison elucidates the rationale behind selecting the bottom-up approach. The act of constructing the model significantly influenced the uniqueness of the research. The chosen approach was demonstrated to have contributed to the attainment of the objective of energy mix predictions that are feasible at the national level, in alignment with the present condition of the energy sector.

The energy system is designed to prioritize the dispatch of energy forms with the lowest net present value of social costs using an optimization framework based on linear programming. This ensures that current energy needs are met efficiently. The research aimed to emphasize the significance of utilizing renewable energy sources and the incentive mechanism for their utilization. The LEAP instrument successfully fulfilled all of the requirements of the conducted energy modeling. To address the issue of the seasonal variability in renewable energy production, one might augment the inherent capability of power plants that generate energy from sustainable sources. This feature offers assistance to the model in the event of unforeseen fluctuations in energy demand and the circumstances surrounding an energy crisis. Furthermore, the LEAP instrument incorporates the utilization of internal capabilities to ensure that the energy reserves remain at the intended level during the energy production process. This is crucial for optimizing the energy development projection model.

The decision to use the LEAP instrument for predicting and optimizing the evolution of the energy sector of Serbia until 2050 was justified, as it successfully incorporated both macroeconomic and microeconomic analyses. The specified software tool allowed for the input of all crucial assumptions, as well as endogenous and exogenous variables of the model. LEAP was chosen for the investigation due of its versatility in analyzing various aspects of the energy system. The successful utilization of the LEAP software instrument may be inferred from its effective implementation in accordance with the predetermined strategy for autonomously developing a distinctive model of future energy flow projections. By utilizing this tool, all pertinent information regarding the operations of the energy industry were incorporated into the empirical study.

Upon performing a thorough analysis of the energy balances, it became evident that both RES utilization alternatives would result in a substantial enhancement to the energy sector's efficiency. However, considering the energy transformation perspective, incorporating the proportional RES capacity in the SCOIE1 scenario would yield more favorable outcomes for the overall sustainability of the system development. The specified option suggests that, during the observed simulation time, there is a requirement to import fossil fuels for their utilization in the conversion process. However, this consumption is significantly reduced because of the increased utilization of RESs. The integration of ideal features would enable the indicated module to be created in compliance with the green energy regulatory policy, facilitating the gradual substitution of outdated technology drives.

It was found that the projection of energy production via transformation yielded some interesting results. This was a category that, within the LEAP instrument, offered the largest degree of flexibility for selecting parameters, with the intention of introducing a number of significant model criteria. As a result, for instance, mandated reserves of renewable energy sources were incorporated into the model. These reserves were considered to be an important measure of strategic link to the transmission system. It turned out that the reserves that were discussed before are especially significant for the assumption of responsibility by privileged electricity producers if there is a decline in production or unforeseen disruptions in the functioning of the power plants that they run. It has been determined, based on the findings of the model, that the capacities that are now available within the national electricity grid transmission of Serbia would not be capable of independently taking on the task of balancing. Two functions were introduced into the model to take into consideration the answer to the problem that was discussed. These functions are the margin of projected energy reserves and the subcategory of energy storage from emerging technologies. From the perspective of the economic analysis of the growth of the energy sector, it was established that the expenses of balancing responsibility should be carried by producers from the field of renewable energy sources. This was proven. All of the other possibilities could result in significant disruptions within the electricity system by the year 2050, as it is currently witnessed.

The aforementioned results indicate once again the importance of this research for key stakeholders from the energy sector in Serbia. A comparative examination of alternative scenarios can produce the following conclusion: if the SCOIE1 scenario is realized, the best degree of energy security and sustainable development of energy from the perspective of energy production by transformation would be attained. This conclusion is based on the results that were presented above. The model demonstrates the significant level of interconnectedness among energy organizations and the potential for a substantial imbalance in the system if business operations do not adhere to the regulations of energy security and value generation for all stakeholders.

In conclusion, the prospects for effective renewable energy generation during the energy transformation are significantly enhanced through the principle of value co-creation. This collaborative framework fosters innovation, inclusivity, and sustainability, ensuring that renewable energy projects deliver maximum environmental, social, and economic benefits. By engaging multiple stakeholders in the co-creation process, renewable energy initiatives can achieve greater acceptance, efficiency, and long-term viability [45,46]. As the world continues to navigate the complexities of the energy transition, embracing value co-creation will be crucial for developing a sustainable project society that not only addresses immediate energy needs but also builds a resilient and equitable future for all [47].

Author Contributions: Conceptualization, N.B., B.I. and N.P.; Methodology, N.B.; Software, N.B., D.M. and Z.R.; Validation, N.M., D.M., Z.R., M.Ć. and J.A.R.; Formal Analysis, N.B.; Investigation, N.B.; Data Collection, all authors; Data Curation, D.M., J.A.R. and N.M.; Writing—original draft preparation, N.B., B.I., N.P. and J.A.R.; Writing—review and editing, B.I. and N.P.; Visualization, N.B., D.M., Z.R. and N.M.; Supervision N.P. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Azar, C.; Dowlatabadi, H. A Review of technical change in assessment of climate policy. *Annu. Rev. Energy Env.* **1999**, *24*, 513–544. [CrossRef]
2. The Breakthrough Institute. Energy Efficiency: Beware of Overpromises. Available online: https://thebreakthrough.org/issues/energy/the-limits-of-efficiency (accessed on 18 March 2024).
3. Stern, D.I.; Burkes, P.J.; Bruns, S.B. The Impact of Electricity on Economic Development: A Macroeconomic Perspective. Available online: https://escholarship.org/uc/item/7jb0015q (accessed on 18 March 2024).
4. Brown, M.A.; Wang, Y. Energy-Efficiency Skeptics and Advocates: The Debate Heats Up as the Stakes Rise. *Energy Effic.* **2017**, *10*, 1155–1173. [CrossRef]
5. Anderson, V. *Energy Efficiency Policies*; Routledge: London, UK, 1993. [CrossRef]
6. Weizsäcker, V.; Lovins, A.B.; Hunter Lovins, L. *Factor Four: Doubling Wealth, Halving Resource Use*; The New Report to the Club of Rome; Earthscan: London, UK, 2006.
7. Mihailova, D.; Schubert, I.; Burger, P.; Fritz, M.M. Exploring Modes of Sustainable Value Co-Creation in Renewable Energy Communities. *J. Clean. Prod.* **2022**, *330*, 129917. [CrossRef]
8. Khawaldeh, H.A.; Shboul, B.; Al-Smairan, M.; Al-Soeidat, M.; Lu, D.; Almomani, F. Comparative Energy and Economic Analysis of Dish Stirling Engine and National Grid Electricity for Residential Building in Mafraq, Jordan. *Sustainability* **2024**, *16*, 5945. [CrossRef]
9. Holechek, J.L.; Geli, H.M.; Sawalhah, M.N.; Valdez, R. A Global Assessment: Can Renewable Energy Replace Fossil Fuels by 2050? *Sustainability* **2022**, *14*, 4792. [CrossRef]
10. Khawaldeh, H.A.; Al-Soeidat, M.; Lu, D.D.-C.; Li, L. Fast Photovoltaic Emulator Based on PV-cell Equivalent Circuit Model. In Proceedings of the Energy Conversion Congress and Exposition—Asia, ECCE Asia 2021, Singapore, 24–27 May 2021.
11. Stevovic, I.; Mirjanic, D.; Petrovic, N. Integration of Solar Energy by Nature-Inspired Optimization in the Context of Circular Economy. *Energy* **2021**, *235*, 121297. [CrossRef]
12. Ryszawska, B.; Rozwadowska, M.; Ulatowska, R.; Pierzchała, M.; Szymański, P. The Power of Co-Creation in the Energy Transition—DART Model in Citizen Energy Communities Projects. *Energies* **2021**, *14*, 5266. [CrossRef]
13. Gronroos, C. Value co-creation in service logic: A critical analysis. *Mark. Theory* **2011**, *11*, 279–301. [CrossRef]
14. Lusch, R.F.; Vargo, S.L. *Service-Dominant Logic: Premises, Perspectives, Possibilities*; Cambridge University Press: Cambridge, UK, 2014.
15. Heuberger, C.F.; Rubin, E.S.; Staffell, I.; Shah, N.; Mac Dowell, N. Power Generation Expansion Considering Endogenous Technology Cost Learning. *Comput. Aided Chem. Eng.* **2017**, *40*, 2401–2406. [CrossRef]

16. Herbst, A.; Toro, F.; Reitze, F.; Jochem, E. Introduction to Energy Systems Modelling. *Swiss J. Econ. Stat.* **2012**, *148*, 111–135. [CrossRef]
17. Adams, T.A. *Modeling and Simulation of Energy Systems*; MDPI eBooks; MDPI: Basel, Switzerland, 2019. [CrossRef]
18. Boonekamp, P.G.M. Price Elasticities, Policy Measures, and Actual Developments in Household Energy Consumption–A Bottom-Up Analysis for the Netherlands. *Energy Econ.* **2007**, *29*, 133–157. [CrossRef]
19. Subramanian, A.S.R.; Gundersen, T.; Adams, T.A. Modeling and Simulation of Energy Systems: A Review. *Processes* **2018**, *6*, 238. [CrossRef]
20. Sanchez-Escobar, M.O.; Noguez, J.; Molina-Espinosa, J.M.; Lozano-Espinosa, R.; Vargas-Solar, G. The Contribution of Bottom-Up Energy Models to Support Policy Design of Electricity End-Use Efficiency for Residential Buildings and the Residential Sector: A Systematic Review. *Energies* **2021**, *14*, 6466. [CrossRef]
21. Böhringer, C.; Rutherford, T.F.; Rutherford, T.F. Combining Bottom-Up and Top-Down. *Energy Econ.* **2008**, *30*, 574–596. [CrossRef]
22. Vogt, Y. Top-down Energy Modeling. *Strateg. Plan. Energy Environ.* **2020**, *24*, 66–80. [CrossRef]
23. Prehofer, S.; Kosow, H.; Naegler, T.; Pregger, T.; Vögele, S.; Weimer-Jehle, W. Linking qualitative scenarios with quantitative energy models: Knowledge integration in different methodological designs. *Energy Sustain. Soc.* **2021**, *11*, 25. [CrossRef]
24. Mata, É.; Sasic Kalagasidis, A.; Johnsson, F. A Modelling Strategy for Energy, Carbon, and Cost Assessments of Building Stocks. *Energy Build.* **2013**, *56*, 100–108. [CrossRef]
25. Grubb, M.; Kohler, J.; Anderson, D. Assessing the Cost of Compliance with Greenhouse Gas Emission Reduction Targets. *Nature* **1993**, *355*, 528–530.
26. Hourcade, J.-C.; Jaccard, M.; Bataille, C.; Ghersi, F. Hybrid Modeling: New Answers to Old Challenges Introduction to the Special Issue of The Energy Journal. *Energy J.* **2006**, *27*, 1–11. [CrossRef]
27. Löschel, A. Technological Change in Economic Models of Environmental Policy: A Survey. *Ecol. Econ.* **2002**, *43*, 105–126. [CrossRef]
28. Seljom, P.; Tomasgard, A. Short-Term Uncertainty in Long-Term Energy System Models—A Case Study of Wind Power in Denmark. *Ecol. Econ.* **2015**, *49*, 157–167. [CrossRef]
29. Koopmans, C.C.; te Velde, D.W. Bridging the Energy Efficiency Gap: Using Bottom-Up Information in a Top-Down Energy Demand Model. *Energy Econ.* **2001**, *23*, 57–75. [CrossRef]
30. Zhang, S.; Liu, P.; Zhang, C.; Shi, Q. Smart Power Consumption in Energy Digital Economy: A Perspective of the Value Co-Creation Mechanism. *Front. Energy Res.* **2023**, *10*, 904260. [CrossRef]
31. Heaps, C.G. LEAP: The Low Emissions Analysis Platform [Software Version: 2020.1.84]. Stockholm Environment Institute. 2022. Available online: https://leap.sei.org (accessed on 4 April 2024).
32. Cai, L.; Luo, J.; Wang, M.; Guo, J.; Duan, J.; Li, J.; Ren, D. Pathways for Municipalities to Achieve Carbon Emission Peak and Carbon Neutrality: A Study Based on the LEAP Model. *Energy* **2023**, *262*, 125435. [CrossRef]
33. Malka, L.; Bidaj, F.; Kuriqi, A.; Jaku, A.; Roçi, R.; Gebremedhin, A. Energy System Analysis with a Focus on Future Energy Demand Projections: The Case of Norway. *Energy* **2023**, *272*, 127107. [CrossRef]
34. Yang, Z. *Strategic Bargaining and Cooperation in Greenhouse Gas Mitigations: An Integrated Assessment Modeling Approach*; The MIT Press: Cambridge, MA, USA, 2008.
35. Stockholm Environment Institute. Long-Range Energy Alternatives Planning System User Guide for LEAP 2005. 2005. Available online: https://unfccc.int/resource/cd_roms/na1/mitigation/Module_5/Module_5_1/b_tools/LEAP/Manuals/Leap_Use_Guide_English.pdf (accessed on 18 March 2024).
36. Ministry of Mining and Energy of the Republic of Serbia. Energy Development Strategy of the Republic of Serbia until 2025 with Projections until 2030. Official Gazette. 2015. Available online: https://www.mre.gov.rs/extfile/sr/5928/Draft%20-%20Energy%20Strategy%2015072024.pdf (accessed on 15 July 2024).
37. Sievers, L.; Breitschopf, B.; Pfaff, M.; Schaffer, A. Macroeconomic Impact of the German Energy Transition and Its Distribution by Sectors and Regions. *Ecol. Econ.* **2019**, *160*, 191–204. [CrossRef]
38. Sterman, J.D. A Skeptic's Guide to Computer Models. In *Managing a Nation: The Microcomputer Software Catalog*; Barney, G.O., Ed.; Westview Press: Boulder, CO, USA, 1991; pp. 209–229.
39. Agencija za energetiku Republike Srbije. *Izveštaj O Radu Agencije Za Energetiku Za 2021. godinu*; Agencija za energetiku Republike Srbije: Belgrade, Serbia, 2022. (In Serbian). Available online: https://www.aers.rs/Files/Izvestaji/Godisnji/Izvestaj%20Agencije%202021.pdf (accessed on 15 March 2024).
40. Sorrell, S. Jevons' Paradox revisited: The evidence for backfire from improved energy efficiency. *Energy Policy* **2009**, *37*, 1456–1469. [CrossRef]
41. Backović, N.; Jakšić, M.; Ilić, B. The Impact of Energy on Climate and Economic Stability: Forecast for Serbia. *J. Cent. Bank. Theory Pract.* **2024**, *13*, 199–222. [CrossRef]
42. Kumar, S.; Madlener, R. CO_2 Emission Reduction Potential Assessment Using Renewable Energy in India. *Energy* **2016**, *97*, 273–282. [CrossRef]
43. Kayo, C.; Tojo, S.; Iwaoka, M.; Matsumoto, T. Evaluation of Biomass Production and Utilization Systems. In *Research Approaches to Sustainable Biomass Systems*; Tojo, S., Hirasawa, T., Eds.; Academic Press: Cambridge, MA, USA, 2014; pp. 309–346. [CrossRef]

44. Fiscal Council of the Republic of Serbia. Opinion on the Draft Fiscal Strategy for 2023 with Projections for 2024 and 2025. 2022. Available online: http://www.fiskalnisavet.rs/doc/ocene-i-misljenja/2022/FS_Mislenje_Nacrt_Strategija_2023-2025.pdf (accessed on 5 May 2024).
45. Prahalad, C.K.; Ramaswamy, V. Co-creation experiences: The next practice in value creation. *J. Interact. Mark.* **2004**, *18*, 5–14. [CrossRef]
46. Gummesson, E. Extending the service-dominant logic: From customer centricity to balanced centricity. *J. Acad. Mark. Sci.* **2008**, *36*, 15–17. [CrossRef]
47. Chesbrough, H. *Open Services Innovation: Rethinking Your Business to Grow and Compete in a New Era*; John Wiley & Sons: Hoboken, NJ, USA, 2011.

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.