Perspectives for Transition to Green Energy in some Regions of Azerbaijan: System Dynamics Approach

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Abstract: - In the paper, the possibilities of transition to the green economy in the areas freed from occupation and large construction works for resettlement, the development of green energy in these areas, and the modeling of the investments required for this purpose for the next 15-25 years have been performed. The System Dynamics simulation method was applied for modeling. The presented model allows calculating the amount of savings in gas resources, the number of "green jobs" created and the economic profit as a result of using the potential of solar energy in areas free from occupation. The paper assesses the resource, technical, and economic potential of solar energy to fully meet the electricity demand through "green energy" in the liberated and rapidly developing East Zangezur and Karabakh economic regions. These projects will be carried out over 15 to 25 years, depending on investment availability and policy changes**.** According to the results, these regions have abundant solar radiation, and an investment of 2.5 billion manats, required to meet the region's electricity needs through solar energy, could yield significant results in a short period of time.

Key-Words: - renewable energy, solar energy, electricity, investments, photovoltaic panels, internal migration, electricity demand, System Dynamics, green jobs, resource potential.

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1 Introduction

The rapid depletion of traditional energy sources, population growth, increasing energy consumption, and environmental issues, such as climate change, have made the transition to renewable energy sources a necessity. Studies by the Intergovernmental Panel on Climate Change (IPCC) demonstrate that renewable energy sources such as wind, solar, and hydropower can significantly contribute to reducing carbon emissions and combating climate change. Unlike hydrocarbons, these sources do not pollute air and water and do not cause significant harm to wildlife and landscapes.

The use of renewable energy is crucial for energy security and independence. According to [1], with current consumption rates, global oil and gas reserves may be depleted in 40-50 years. Investing in renewable energy allows countries to reduce their dependence on imports, which are often subject to volatile prices and geopolitical tensions. Furthermore, the expansion of renewable energy leads to economic growth and job creation, while operational costs are significantly lower than those of traditional energy systems.

Investing in renewable energy also fosters technological advancement and improves energy infrastructure. Technological innovations lead to the development of more efficient energy production, storage, and distribution systems, which positively impact both economic development and environmental sustainability.

Given the importance of renewable energy, countries like Azerbaijan are actively developing projects in this field. This is very necessary for the energy security of Azerbaijan [2] and environmental protection [3], **Σφάλμα! Το αρχείο προέλευσης της αναφοράς δεν βρέθηκε.**. In 2016, the "Strategic Roadmaps" approved by the President of Azerbaijan identified renewable energy as a priority for economic development. The document "Azerbaijan 2030: National Priorities for Socio-Economic Development" also emphasizes the transition to a "green economy" as a national priority.

After the liberation of the territories of Azerbaijan occupied by the Armenian army for nearly thirty years, a new era for the repopulation of these regions began. However, the complete destruction of these areas and the destruction of all infrastructures gave a new character to the reconstruction process. In completely destroyed areas, and in most cases in mined areas, it was important to clear the areas of mines and debris for reconstruction, and then to lay the necessary infrastructures, especially roads, electricity, and water lines. Although the construction of such infrastructures, as well as the subsequent settlement of completely empty areas, require large costs, they provide favorable opportunities for the application of new technology and innovative management in the work process. One such spell is related to the application of the green economy model.

"Green economy" is closely related to the concept of "sustainable development". Among the many determinants on which it depends, "use of green energy", "reduction of carbon emission" and "reduction of the use of hydrocarbon resources" are the main ones. Among the "green energy" sources, solar and wind energy attract more attention for regions liberated from occupation. So, in these regions, solar radiation is more abundant and there is a favorable opportunity to convert solar energy potential into technical potential. Undoubtedly, in these areas, which make up 20% of the territory of Azerbaijan, it is impossible to implement neither the settlement nor the complete transition to green energy in a short time, for example, in 3-5 years. In these areas, the construction of necessary infrastructures, as well as settlement and creation of new jobs, require a large amount of investment. Even the necessary amount of investment does not allow the planned works to be completed in a short time. Because the relocation of people settled in various regions of the country over the past 30 years within a short period of time may have a significant impact on the labor market.

The settlement process in the territories freed from occupation is implemented and regulated by the "I State Program on the Great Return to the territories freed from occupation of the Republic of Azerbaijan" approved by Decree No. 3587 of the President of the Republic of Azerbaijan dated November 16, 2022. The State Program first envisages the creation of the necessary infrastructure and the gradual relocation of the population to these areas. Population migration will increasingly increase the demand for electricity from new households and new businesses. The increase in demand for electricity will not be without impact on investment in electricity industry, **Σφάλμα! Το αρχείο προέλευσης της αναφοράς δεν βρέθηκε.**.

Since the immediate consideration of all the necessary determinants during the modeling of the transition to the "Green economy model" in the liberated territories complicates the model, we will mainly consider the change of 3 determinants: a) use of solar energy; b) saving gas fuel; c) reducing carbon emissions. However, all three of these determinants depend on the level of settlement in the area. Therefore, there is a need to model settlement in the area first.

The use of renewable energy is particularly relevant for the reconstruction and development of liberated territories. These areas, part of the Karabakh and East Zangezur economic regions, have significant potential for renewable energy, particularly solar. Efficient use of these resources will ensure sustainable development and economic benefits.

2 Literature Review

Population migration to the liberated territories of Azerbaijan can be considered as internal migration in modeling. As a result of such migration, the number of population to be resettled will tend to decrease in the areas where they currently live, and increase in the areas to which they are resettled. Modeling the flow from one area to another as a result of migration has been studied in the example of different countries. For example, **Σφάλμα! Το αρχείο προέλευσης της αναφοράς δεν βρέθηκε.**, [7], [8] and others have performed modeling of internal migration processes.

The expansion of renewable energy sources (RES) is imperative. As mentioned earlier, this necessity is primarily driven by energy security concerns and environmental challenges. While countries rich in oil do not face significant energy security issues, they are still working to develop RES, taking into account strategic goals and economic efficiency. Economic and technological development history proves that a lack of investment in innovation at any given moment can harm a country's future competitiveness. Lost time cannot be regained.

In recent decades, many studies have been conducted on the assessment of RES, including the potential of solar energy in different countries. For example, research by [9], [10], [11], [12], [13], [14], [15], [16] and many others demonstrate the significant technical and economic potential of solar energy. The potential of solar energy in Azerbaijan was studied by [17].

3 Methodology

Based on this, it can be argued that any country leading in the development of RES will play a dominant role in the future energy market. Thus, answers to key questions about RES, including solar energy, may serve as motivation for its use. The primary question is how efficient solar energy use is. In other words, can the cost of energy generated by solar panels be compared with the current market price of electricity? Of course, the answer depends on several factors, which can be grouped as follows:

a) What is the solar energy resource potential in the region?

b) To what extent can current technologies convert this resource potential into technical potential, i.e., how much energy can be produced with solar panels?

c) What is the cost of solar panels and their installation?

d) What is the cost of the energy generated by solar panels at current market prices?

e) How much fuel can be saved by using solar panels, and what profit can be gained from selling this amount of fuel?

f) How much CO_2 emissions can be avoided by replacing this fuel with solar energy?

g) How many jobs can be created by using solar energy?

The first two questions (a and b) deal with the conversion of resource potential into technical potential, the third (c) addresses the total cost of obtaining solar energy, and the remaining four (d, e, f, g) describe possible revenues and benefits. When evaluating efficiency, it is crucial to ensure that revenues exceed costs. It is important to note that investments in solar panels are long-term, and immediate returns are not expected. However, investing part of the revenue in such long-term projects is advisable.

In economic literature, resource potential is often evaluated as the foundation for RES, [18], [19], **Σφάλμα! Το αρχείο προέλευσης της αναφοράς δεν βρέθηκε.**. Resource atlases have been developed for some regions, [21], [22], [23], [24], etc. Solar energy's resource potential is higher than that of other energy sources, but fully realizing this potential for consumer use is impossible, as panels cannot be installed in all areas considered in resource assessments.

3.1 Solar Energy: Resource Potential

The resource potential of solar energy in any country, region, or specific area refers to the amount of energy produced by solar radiation in that geographical location. This volume is typically measured in kWh. The solar energy resource potential can be expressed as:

$$RP_{se} = S \times H_r \times T_s \tag{1}$$

where: RP_{se} — theoretical solar energy resource potential for any area; S— area size (km²); H_r - solar radiation intensity (MW/km²); T- number of sunlight hours per year.

3.2 Solar Energy: Technical Potential

For calculating the technical potential of solar energy, [25] proposed comparative pricing methods. [26] used a "solar array model." According to this model, the technical potential of solar energy refers to the amount of energy that can be achieved in a given array, taking into account photovoltaic technology and other factors, such as energy losses due to weather conditions and cooling requirements. Thus, the technical potential of solar energy for the entire country can be calculated based on these parameters.

$$E_A = \sum_{j=1}^{n} \sum_{i=1}^{N} SETP_{ij} = \sum_{j=1}^{n} \sum_{i=1}^{N} (S_{ij} - F_{ij} - HM_{ij} - WB_{ij}) \times (C_{ij} + SHC_{ij}) \times \eta_P \times \left(1 - \lambda_p\right) * (1 - \lambda_C) \tag{2}$$

Here, $SETP_{ij}$represents the total technical potential of the j- group of solar radiation in the i -

region; F_{ij} $HM_{ij} - WB_{ij}$- is the area of the i district belonging to the j- solar radiation group. According to the data, C_{ij}- and SHC_{ij}represent the forest area, highland zones, and bodies of water in the j radiation group in the i- district. H_R - Represents the total amount of radiation in clear and partly cloudy conditions in the j radiation zone of the i district. This can also be considered as H_R— the total volume of radiation. η_P refers to the efficiency of the solar modules, and $\lambda_p$represents losses due to various factors, including surface contamination of photovoltaic panels (commonly accepted as 10%). λ_C- PV accounts for cooling losses (commonly set at 5%).

In assessing the technical potential, it is essential to consider which areas are suitable for utilizing the theoretical potential based on current technical capabilities, [27]. This condition serves as a constraint when evaluating the technical potential, as the presence of certain infrastructure can limit the use of land for solar panels. For example, installing photovoltaic panels may be difficult on highways, agricultural lands, water bodies, national parks, and mountainous regions. These areas should not be considered when calculating the solar energy resource potential. Instead, calculations should be based on areas that can be used for technical facilities.

We will use the System Dynamics method to model the relocation of the population to the liberated regions of Azerbaijan and the satisfaction of this population's demand for electricity. This method uses instruments such as "stocks", "flow", "auxiliary variables" and "feedback". According to the set goal, we can take "potentialmigration" (ready to move) population and "population" (migrated population) as "stocks". The connection between these two "stocks" is connected through the "flow" of "migration". Both "potentialmigration" and "population" "stocks" can be increased by "migrationbirth" and "birth" flows (newbirths) and decreased by "migrationdeath" and "death" flows (new deaths), respectively.

During the construction of the model, we will accept the following assumptions for simplicity: 1) we will assume that the birth and death rates in populated areas are at the average level for the country; 2) the amount of demand for electricity in populated areas is at the level of the average demand for the country; 3) the number of people resettled every year is equal; 4) complete resettlement will be carried out within 10 years; 5) each PV panel to be used is 500W; 6) the number of sunny days is equal across the region; 7) the salary in the electricity sector in the region is equal to the average salary in this sector; 8) the number of people working in the electricity sector in the region is the number corresponding to 1MWh of energy production in this sector.

Taking into account the assumptions mentioned above, we will try to build a model for the transition to a green economy model in the liberated territories on the basis of System Dynamics modeling.

3.3 Current Situation of Solar Energy Use in Azerbaijan

Since the second half of the last century, theoretical and practical work has been carried out in Azerbaijan in the field of solar energy utilization. Despite significant efforts in the past 20 years to develop solar energy in Azerbaijan, this type of renewable energy still has a minimal share in the country's overall energy production. In 2023, solar energy accounted for less than 0.3% of total energy production, even though its share has increased over 247 times since 2013. However, this figure remains significantly lower compared to countries with the highest number of photovoltaic panels, such as China (176,100 MW), the USA (62,600 MW), Japan (56,000 MW), Germany (45,400 MW), India (32,900 MW), Italy (20,100 MW), the UK (13,000 MW), Australia (11,300 MW), France (9,000 MW), and South Korea (7,900 MW), [28]. In these countries, solar energy accounts for: China — 10%, USA — 6%, Japan — 17%, Germany — 22%, India — 11%, Italy — 17%, UK — 14%, Australia — 17%, France — 7%, and South Korea — 8%, [29].

3.4 Solar Energy Resource Potential in Karabakh and East Zangezur Economic Regions

To calculate the solar energy (SE) resource potential in the economic regions of Azerbaijan, we consider solar radiation data and the distribution of sunlight hours. As highlighted in the studies by [30], the average annual number of sunlight hours in Azerbaijan ranges from 1900 to 2800 hours depending on the region, and the territory can be divided into seven different groups based on solar radiation levels.

For the Karabakh and East Zangezur economic regions, the average annual number of sunlight hours is between 1900 and 2200. According to Shikhlinsky's data, the total radiation level in this area is 120–125 kcal/cm², which corresponds to 1400–1440 kWh/m² per year. Example Calculation for Karabakh Region: Area (S): For example, if the area of the Karabakh region is 5000 km². Solar Radiation Intensity (Hr): The average radiation in the region is 1440 kWh/m² per year. Number of Sunlight Hours (Ts): We assume an average of 2100 hours per year. Substituting the values into the formula:

$$RP_{se} = 5000\ km^2 \times 1440\ kWh/m^2 \times 2100\ \text{hours per year}$$

This calculation gives us an estimate of the potential energy that could be harnessed from solar radiation in the Karabakh region, assuming all available land is utilized.

Thus, the calculation of solar energy resource potential for Azerbaijan's economic regions, such as Karabakh and East Zangezur, shows significant potential, especially considering the long hours of sunlight and high radiation levels (Table 1, Appendix).

3.4.1 Technical Capabilities

It is realistically impossible to fully utilize the theoretical solar energy potential for several reasons:

1. Installation limitations: Solar panels or collectors cannot be installed on every square meter of the country's land, including mountainous areas, forests, water bodies, areas under high-voltage power lines, urban parks, and other important locations.

2. Limited equipment efficiency: Modern solar panels and collectors are unable to fully convert solar radiation into electrical or thermal energy. Currently, the average efficiency of photovoltaic (PV) panels is about 20%, and for solar collectors, it is 50%. The term "average" is used here because the efficiency of PV panels varies with weather conditions, while the efficiency of collectors depends on their temperature.

Given that the primary future application of solar panels will be electricity generation, we will use an efficiency rate of 20% in calculating the technical potential. Available land for installation must also be considered when calculating the technical potential of solar energy. In Azerbaijan, there are high-altitude areas that are unsuitable for residential construction or solar installations. These areas should be excluded from the technical potential calculations. The second formula is used for calculating the technical potential.

The area of forest massifs, high mountain massifs and water basins in individual regions included in the composition of economic districts is mainly considered as non-cultivated area. Placing solar PV panels in such areas is not advisable. On the other hand, since farmlands are also important for food security, these areas cannot be used entirely for solar panels. It is more appropriate to place such panels on less quality farmland and above residential buildings. Although quantitative evaluation of such areas is important for research, in the initial approach, this area can be accepted in areas close to settlements and 5% of the total area of the district. This percentage may vary depending on the purpose of using solar energy. So, if there is full settlement in Eastern Zangezur and Karabakh economic regions, it can be assumed that the average electricity consumption for the country will be fully (100%) provided by solar energy. In this case, the area should be allocated for solar power plants in such a way that the technical potential exceeds the consumption volume and can fully meet the demand. It should be noted that currently the production volume of electricity in the country is 29.3 million MWh. Electricity consumption per person is 2.7 MW*h. Therefore, in the regions involved in the study, it is possible to fully meet the region's electricity demand by obtaining 2.7 MW*h per person from solar energy. In the case of full settlement in the Eastern Zangezur economic region, 0.82 million MWh of electricity may be required, and 2 million MWh of electricity in the Karabakh economic region. Taking into account the assumptions we mentioned, we can simplify the identity (8) a little:

$$SETP_i = \sum_1^n \alpha * S_i * ((C_i + SHC_i) * \eta_P * (1 - \lambda_p) * (1 - \lambda_C) \quad (3)$$

Here $SETP_i$ technical potential in i- district; α*S_i-th area of the area included in the solar radiation group of the i-th region for solar batteries; C_i, SHC_i- is the total amount of radiation in the radiation zone of the i-th district, in open air and semi-cloudy air, respectively. η_P - efficiency module (usually taken as 40%-50%); λ_p- module of losses caused by various reasons, including losses caused by contamination of the surface of PV batteries (usually taken as 10%); λ_C - are losses for cooling of PV batteries (usually these losses are taken as 5%).

Thus, we will consider solar radiation in two groups: a) "Direct solar radiation falling on a horizontal surface in open air (Watt/m^2)" b) Direct solar radiation falling on a horizontal surface in partly cloudy weather (Watt/m^2). We will consider that Solar panels will be placed mainly in horizontal areas. In the first case, it is estimated at 604-628 W/m^2. We will consider that the radiation level in the areas included in the Eastern Zangezur and Karabakh regions does not differ significantly taking into account prices and simplification, we can estimate the technical potential of solar energy for East Zangezur and Karabakh economic regions as in Table 2 (Appendix). The α calculated during the evaluation is allocated for solar power plants to provide 100% of the electricity needs of the administrative regions included in these economic regions. represents the share of the possible area in the total area.

4 Economic Potential

The electricity sector in Azerbaijan is in the natural monopoly of the state. Therefore, the price of electricity is below the possible price of the market, [31]. Because it is a natural monopoly, the price of electricity from solar energy will be significantly higher. Therefore, the use of renewable energy sources should be implemented with the support of the state.

When calculating economic potential a) total technical potential ($SETP_i$); b) Gas saving in the TPP (NE_i); c) price of saved fuel (PFF_i); d) number of (300Watt) (PV_i); e) total price (with installation) (mln.azn) (PPV_i); f) GES development and maintenance cost in 1 year (mln.azn) (TNE_i); g) Total possible expenses for GES in 30 years (mln.azn) (TC_i); h) GES potential income (TR_i) ; in 30 years; j) Potential profit (mln.azn) (π_i) indicators will be used in 30 years. The power of each panel is 300 W, 1000 m2 area will be taken for each 100 panels. The activity period of the panels will be considered 30 years. In the initial approach, we will consider that since the GES invested by the state, no discount will be calculated for this investment. We will consider that the price of saved gas will not change and will be 0.2 manat per cubic meter. We will also consider that 780 manats are spent for the installation of 1 panel.

As we mentioned above, a very ambitious goal has been set on the basis of the calculations: providing 100% of the electricity demand in the East Zangezur and Karabakh economic regions from solar energy. The fact that the resource potential of solar energy in these regions is very high creates confidence in the possibility of realizing such an ambitious goal. The next steps, i.e. the calculations for the transformation of resource potential into technical potential and then into economic potential, also show that the realization of the goal is also technically possible. So, on average, 3-5% of the total area of these regions can be allocated for the installation of solar panels. On the other hand, calculations show that obtaining 100% of the electricity required in these regions from solar energy does not cause economic loss, but rather brings additional income (Table 3, Appendix). According to the calculations made at current prices, the total profit for East Zangezur economic region in 30 years can be 350 million Azn, and for Karabakh economic region 1.6 billion Azn. On the other hand, environmental cleanliness can be achieved in these areas. New "green jobs" are overrun. An investment of 2.5 billion USD required for the transition to a green economy in the liberated territories will be directed towards the purchase and installation of solar panels.

As we mentioned above, people who live in different regions of Azerbaijan, mainly in Baku, but are ready to move to regions free from occupation, will be expressed as "stocks" in the System Dynamics model. According to the 2024 data of [32], this "stocks" is 367,000 people in the Karabakh economic region and 302,000 in the East Zangezur economic region. The population of Aghjabedi, Barda and Tartar regions, which are included in the Karabakh economic region, are not included in these figures. However, if the transition of Karabakh and Eastern Zangezur economic regions to the green economic model is envisaged, then their number can be included in the model as a preliminary indicator in the "population" stocks. According to Figure 1 in Appendix, we will use the following functions:

$$\text{a)}\, potentialmigrants = f(migrantbirth, migrantdeath, migration, initialmigrants);$$
$$b) migrantbirth = f(birthrate, potentialmigrants);\ c) migrantdeath = f(deathrate, population);$$
$$d)\ population = f(migration, birth, death).$$

Figure 1 in Appendix shows that both "stocks" depend on birth and death rates, among other indicators. This means that there are changes related to births and deaths in the population, both those who are preparing to move and those who move. Such changes change the population's demand for electricity. Taking this into account, additional variables of total demand for electricity ("$totalelectdemand$") and demand for electricity per person ("$elecdemandpercap$") were included in the model. These indicators are country-specific indicators and are included in the model as constants. As the number of people moving to the territory liberated from occupation changes, the total electricity demand of this population will also change. Undoubtedly, as the "population" resource increases, the "$electricity\ demand$" indicator will also increase (Figure 1, Appendix).

The increase of this reserve also plays an important role in the increase of the labor force in the region. Taking these into account, the electricity demand ("$electricitydemand$") and the labor force ("$laborforce$") indicator were added to the simulation model, respectively,

$$e)\ electricitydemand = f(population, elecdemandpercap),$$

i.e., the per capita demand for electricity from the number of residents and the country volume dependent function;

$$f) labourforce = f(population, labourparticipate),$$

that is, we can enter it as a function depending on the number of migrated population and the labor participation rate for the country.

We can also include in the SD model the resource and technical potential of solar energy in the region. According to this model, the resource potential is a) from the territory of the region; b) radiation level; c) depends on the number of sunny days:

$$resourcepotentialofSE = f(territoryofregion, radiation, quantityofsunnyhours).$$

The technical potential of solar energy depends on a) amount of sunny hours in the region; b) from the number of cloudy hours; c) from the amount of radiation on sunny days; d) from the amount of radiation on cloudy days; e) efficiency of the module; f) from the amount of loss in PVs; g) losses during cooling; h) Depends on the area allocated for PV:

$$technicalpotentialofSE = f(territoryofregion, quantityofsunnyhours, radiationofsunnydays, radiationofcloudydays, efficiencymodul, lossesofPV, lossincooling).$$

Note that by including the indicators and sub-model in Figure 1 (Appendix) in the final simulation model, it is possible to calculate the size of the area allocation to obtain the required level of GE in each region. On the other hand, the number of PVs to be installed also depends on the technical potential. Considering the $shareofSE$ variable, PV installation and economic benefits can be predicted by planning which part of the region's electricity demand will come from solar energy (Figure 1, Appendix). The dependence of the number of PVs mainly on three indicators is reflected in the sub-model. According to Figure 1 (Appendix),

$$numberofPV = f(demandedSE, powerofPV, quantityofsunnyhours)$$

Another important sub-model included in the model is shown in Figure 1 (Appendix). In this sub-model, the costs necessary to use solar energy and the savings in gas fuel are reflected. According to this sub-model, the purchase and installation of a certain number of PV panels, as well as the servicing of these panels are provided.

The installation and maintenance of PVs is reflected in the variable $totalcostofconstPV$. This variable is based on a) the number of jobs opened at different levels in solar energy stations; b) from the average salary in this sector; b) from the number of PVs; c) depends on the costs of installing PVs:

$$totalcostofconstPV = f(numberofPV, jobsinSE, costofPV, costofconstPV, avaragesalary)$$

The sub-model in Figure 1 (Appendix) also allows calculating the economic efficiency of using solar energy. In this sub-model, the function

$$economicpotentialofSE = f(economtogas, priceofgas, totalcostofconstPV)$$

allows to calculate the economic efficiency of solar energy production for each region in any year.

The complete simulation model resulting from the combination of the above-mentioned sub-models for the use of green energy is given in scheme 8. The limitations of this model are based on the assumptions we mentioned above. However the advantages are that by changing the constants, the economic benefits of using solar energy in any region can be predicted.

4.1 Some Limitations of the Study

It should be noted that there are some limitations in the study that somewhat hinder the accuracy of the results obtained: for example,

a) in the study, the case of complete settlement in Eastern Zangezur and Karabakh economic regions was taken. However, it should be taken into account that full settlement is not possible at once and it will take several years;

b) in the study, in accordance with the full population, when calculating the demand for electricity, the average consumption volume per person in the country was taken. However, most likely, the main demand for electricity in these areas will be from households;

c) during the calculation of solar radiation, the number of sunny days and the intensity of solar radiation in the territory of both economic regions, as well as in the territory of administrative regions, were taken as the same. However, in reality, there may be certain differences, and in some cases drastic differences. For example, the intensity of solar radiation in the Fuzuli or Barda regions and the solar intensity in the Kalbajar region may be different.

d) the cost of buying and installing solar panels, as well as the salary of employees during the 30-year operation of these panels may change. Because inflation or the increase in average salary that occurs every year can change these indicators.

Taking into account the above-mentioned limitations in the present study could have made it more complicated. Taking this into account, the research calculated the resource, technical, and economic potential of solar energy in East Zangezur and Karabakh economic regions and confirmed the possibility of providing the demand for electricity from a fully renewable source. There is a need to continue research in this area with more accurate methods and taking into account all determinants.

5 Conclusion

Modeling the use of solar energy in the freed Karabakh and Eastern Zangezur economic regions with the System Dynamics simulation method allows us to predict the economic potential of using solar energy according to the population level for each year. The simulation method allows us to determine how much area to allocate and how much investment to PV in these economic regions, and even in individual administrative regions included in them, to replace 0-100% of the demand for electricity with solar energy. Also, the SD model allows predicting the use of solar energy for the long term. Calculations based on such a simulation model show that 100% payment of the demand for electricity through solar energy within 30 years (i.e. the heating period of PVs) allows not only to pay back the investment in full but even creates an additional profit of 15-20%.

The calculation of the resource, technical, and economic potential of solar energy for East Zangezur and Karabakh economic regions shows that the amount of electricity required during the full settlement of these regions can be obtained completely (100%) through solar panels. Calculations show that 965.82 million AZN and 1655.11 million AZN (approximately 2.5 billion AZN) should be invested in these regions in order to fully meet the demand for electricity in Eastern Zangezur and Karabakh economic regions from solar energy. At first glance, these funds, which can be considered as a large amount, lead to the saving of gas fuel for both economic regions and the creation of new jobs ("green jobs") in these regions. The savings on gas fuel are quite large and justify the amount of investment. Thus, for the East Zangezur economic region, this figure is 36 million manats per year, making it more than 1 billion manats in 30 years. For the Karabakh economic region, this figure is 88 million manats per year and exceeds 2.5 billion manats in 30 years. The investment of 2.5 billion manats, directed for the first time to the full supply of electricity for these two economic regions, may be reduced in the following years as a result of the cost of installation the further cheapening of the panels, and the increase of the useful work coefficient. As a result, the benefits of replacing thermal electricity with solar energy can increase.

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- Jafarova R.: Writing - original draft;
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APPENDIX

Table 1. Solar Energy Potential in the Economic Regions of Azerbaijan

Name of the districts	Territory of the district	Intensity of solar rays (KWh/m2)	Number of sunshine hours (hours/year)	SE capacity (MW*h/year)
	S_i (km^2)	H_r^i	T_s^i	RP_{se}^i
East-Zangazur economic region				
Jabrayil district	1050	*1440*	*2300*	*3,4776E+12*
Kalbajar district	2314	*1440*	*2300*	*7,66397E+12*
Gubadli district	802	*1440*	*2300*	*2,65622E+12*
Lachin district	1835	*1440*	*2300*	*6,07752E+12*
Zangilan district	730	*1440*	*2300*	*2,41776E+12*
Total for East-Zangazur economic region	***6731***	***1440***	***2300***	***2,22931E+13***
Karabakh economic region				
Khankendi city	*29,12*	1440	2300	*96445440000*
Agjabadi district	*1760*	*1440*	*2300*	*5,82912E+12*
Aghdam district	*1150*	*1440*	*2300*	*3,8088E+12*
Aghdara district	1660,83	*1440*	*2300*	*5,50067E+12*
Barda district	*957*	*1440*	*2300*	*3,16958E+12*
Fuzuli district	*1386*	*1440*	*2300*	*4,59043E+12*
Khojaly district	*970*	*1440*	*2300*	*3,21264E+12*
Khojavand district	*1458*	*1440*	*2300*	*4,8289E+12*
Shusha district	*310*	*1440*	*2300*	*1,02672E+12*
Tarter district	*960*	*1440*	*2300*	*3,17952E+12*
Total for Karabakh economic region	**10640,95**	***1440***	***2300***	***3,52428E+13***

Note: Calculated by the authors

Table 2. Technical Potential of Solar Energy in the Economic Regions of Azerbaijan

Name of the districts	Demand by region (based on national average) (MW*h/year)	total outdoor radiation (W/m2) -C_i	Total radiation in partly cloudy weather - W/m2SHC_i	The total area of the districts (km^2)	Area required to be allocated for PV (m^2)($\alpha * S_i$)	α
Jabrayil district	197370	604-628	242-266	1050	56173155,7	5,3
Kalbajar district	199530	604-628	242-266	2314	56787909,8	2,5
Gubadli district	100170	604-628	242-266	802	28509221,3	3,6
Lachin district	204390	604-628	242-266	1835	58171106,6	3,2
Zangilan district	115290	604-628	242-266	730	32812500,0	4,5
Total for East Zangezur economic region	**816750**	**604-628**	**242-266**	**6731**	**232453893,4**	**3,5**
Khankendi city	11880	604-628	242-266	29,12	3381147,5	11,6
Agjabadi district	367470	604-628	242-266	1760	104585041,0	5,9
Aghdam district	485460	604-628	242-266	1150	138165983,6	12,0
Aghdara district	n/a	604-628	242-266	1660,83	n/a	m/y
Barda district	423630	604-628	242-266	957	120568647,5	12,6
Fuzuli district	353160	604-628	242-266	1386	100512295,1	7,3
Khojaly district	41580	604-628	242-266	970	11834016,4	1,2
Khojavand district	33210	604-628	242-266	1458	9451844,3	0,6
Shusha district	67770	604-628	242-266	310	19287909,8	6,2
Tarter district	217350	604-628	242-266	960	61859631,1	6,4

Total for Karabakh economic region	**2001510**	**604-628**	**242-266**	**10640,95**	**569646516,4**	**5,4**

Note: calculated by the authors

Table 3. The economic potential of GE in the economic regions of Azerbaijan

districts	$SETP_i$	NE_i	PFF_i	PV_i	PPV_i	TNE_i	TC_i	TR_i	$\pi_i = TNE_i - C_i$
	MWh	Mln.m^3	Mln.azn	ədəd	Mln.azn	Mln.azn	Mln.azn	Mln.azn	Mln.azn
Jabrayil	197370	43,42	8,68	225002	175,82	1,92	233,39	260,53	84,71
Kalbajar	199530	43,90	8,78	227464	177,74	1,94	235,95	263,38	85,64
Gubadli	100170	22,04	4,41	114194	89,23	0,97	118,45	132,22	42,99
Lachin	204390	44,97	8,99	233005	182,07	1,99	241,70	269,79	87,73
Zangilan	115290	25,36	5,07	131431	102,70	1,12	136,33	152,18	49,48
Total for East Zangezur ER	**816750**	**179,69**	**35,94**	**931095**	**727,56**	**7,94**	**965,82**	**1078,11**	**350,55**
Khankendi city	11880	2,61	0,52	13543	10,58	0,12	14,05	15,68	5,10
Agjabadi	367470	80,84	16,17	418916	327,34	3,57	434,54	485,06	157,72
Aghdam	485460	106,80	21,36	553424	432,45	4,72	574,07	640,81	208,36
Aghdara	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Barda	423630	93,20	18,64	482938	377,37	4,12	500,95	559,19	181,82
Fuzuli	353160	77,70	15,54	402602	314,59	3,43	417,62	466,17	151,58
Khojaly	41580	9,15	1,83	47401	37,04	0,40	49,17	54,89	17,85
Khojavand	33210	7,31	1,46	37859	29,58	0,32	39,27	43,84	14,25
Shusha	67770	14,91	2,98	77258	60,37	0,66	80,14	89,46	29,09
Tarter	217350	47,82	9,56	247779	193,61	2,11	257,02	286,90	93,29
Total for Karabakh ER	**2001510**	**440,33**	**88,07**	**1370897**	**1071,22**	**19,46**	**1655,11**	**2641,99**	**1570,77**

Note: calculated by the authors

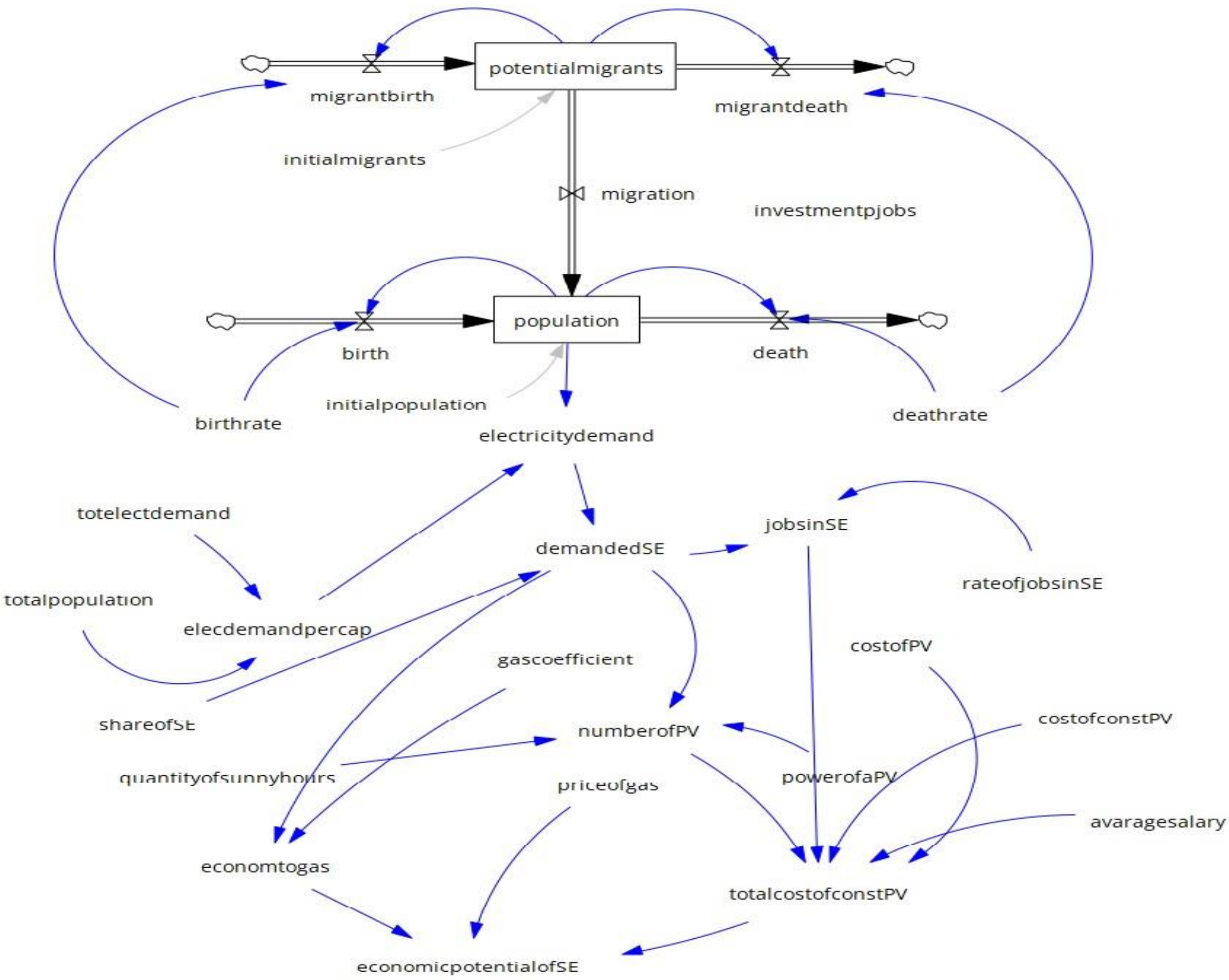

Fig. 1: SD model that assumes solar energy and reduced gas usage