Developing a systems dynamic model to capture NEXUS interactions and help to promote sustainable development in Azerbaijan

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ABSTRACT

The objectives of this work are to investigate water, land, food, energy sectors of Azerbaijan, analyze their effect on the climate of the country, determine the key links between these sectors and understand the dynamics between them using System Dynamics Modeling (SDM). The results of the SDM for every sector from 2017 to 2050 were discussed. Moreover, the solutions, recommendations and policy insights that could be useful to make effective policy decisions to push Azerbaijan towards low-carbon and sustainable economic development are proposed.

KEYWORDS: Sustainable Development; Low-carbon Economy; Azerbaijan; System Dynamics Modeling (SDM).

1 INTRODUCTION

The transition towards a low-carbon economy is a vital opportunity for every country to contribute to the transformation of the global energy market to a more sustainable one and play a role in mitigating climate change. Strong coordination between capital, technology and policy as well as cooperation between private and public sectors are required for achieving the low-carbon economy. The challenge is further exacerbated when the economic growth of the country heavily relies on fossil fuels, which is the case in Azerbaijan. However, challenges in the country regarding the low-carbon economy should not only be associated with fossil fuels but should be analyzed by integrating several sectors that are making up the economy and investigating the dynamics between them. Thus, this study investigates Azerbaijan's transition to a low carbon pattern as one of the 12 case studies of Sustainable Integrated Management for the Nexus of Water-Land-Food-Energy-Climate (SIM4NEXUS) project (SIM4NEXUS, 2019).

The Nexus segments are interconnected with each other and alternations in one can lead to changes in another (Domingo, 2017). Hence, to overcome the complexities of having several dynamically connected sectors, system dynamics modeling (SDM), which is an approach to understand and model nonlinear behavior of complex multi-component systems over a certain timeframe (Zarghami & Akbariyeh, 2011), is used in this study.

The SDM forecasts for every segment from baseline year (2017) to 2050 are discussed.

Finally, recommendations on energy and agricultural sectors are presented together with solutions to change the data quality issues and pollution permits in Azerbaijan.

2 METHODOLOGY

The work has been separated into several milestones to achieve the objectives of the study. The first step was designing the structure of the SDM for every segment and setting the timeframe. The next step was the collection of the data for each segment to populate the model which was followed by verifying and running the model. Finally, the results for each sector of the NEXUS were obtained.

2.1 System Dynamics Model (SDM) Structure

The SDM is designed to contain all five segments of the NEXUS and the interconnections between those.

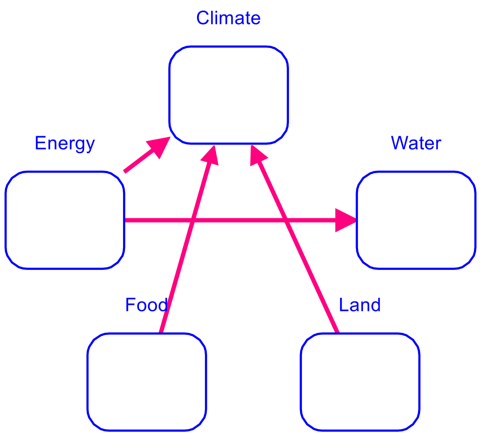

Figure 1 Structural Overview of the Highest Level SDM of Azerbaijan

As can be seen in Figure 1, the energy, food and land segments have an impact on the climate sector while energy is also interlinked with the water segment. The main idea in designing the SDM for every segment is to maintain the balance between available resources and demand for them. The links between the segments and dynamics in the model are analyzed in this chapter of the report.

Water Segment – The initial balance in this sector is set to zero and the groundwater, surface water resources, as well as recycled water, are combined as available water. However, domestic, agricultural and industrial water demand are included on the demand side of the model. Finally, water consumption in the cooling processes of the energy production systems is included in the SDM.

Land Segment – Here, the irrigated, non-irrigated and fallow land as well as the area covered by wetlands and forests are considered as a part of the total land use. Moreover, the land utilized for livestock is also included as an input to the total land use.

Food Segment – The food products are divided into grain, vegetable, fruit, meat, dairy, and other basic food products categories. The SDM for this section was also divided into available food and food consumption. In the available food section, food stocks at the beginning of each year, the production and imports of the food products are summed to obtain the total resources for the food products. In the food consumption section, however, the use of food products, their exports, losses, and stocks at the end of a year are accumulated.

Energy Segment – In the energy segment of the model, the balance between the available energy and the energy demand is followed. Available energy is segregated into energy produced from fossil fuels (oil and gas) and renewable energy sources (hydro, wind and solar energy). On the demand side, energy consumption in the residential, service, agricultural, industrial and transportation sectors is included.

Climate Segment – The climate segment is the final segment of the SDM which is directly linked to land, food and energy sectors. This part of the model is designed to balance the GHG emissions and sequestration. The sequestration side of the balance links this section of the model with the Land segment as both forests and fallow lands are sequestering the GHGs. The emission side, however, builds a dynamic connection between the food and energy segments with the climate sector.

2.2 Data Collection

After the determination of the final structure of the model, the data was collected for each segment. The data was collected considering 2017 as the baseline year for all the segments with projections to 2030 and/or 2050.

2.2.1 Water Resources, Use and Projections

Total water resources of the country are estimated to be about 39.9 km^3 of which 30.9 km^3 is surface and 9 km^3 is ground (Imanov & Alekberov, 2017). The surface water, which comprises rivers, lakes, water reservoirs and glaciers, are used for the irrigation, agricultural and industrial use. However, groundwater is not widely used.

Per capita water consumption is 1313 million m3/year which makes Azerbaijan one of the countries with the lowest available water resources. Irrigation and agriculture use 6570 million m3/year of the surface waters while 2224 million m3/year is used for industrial purposes. (Water Resources , 2019)

Although no significant changes are expected in groundwaters, surface waters are forecasted to decrease by 23% compared to the baseline year. The available water per capita is projected to decrease by 60% (WorldBank, 2012). The agricultural and industrial use of water, however, is forecasted to increase by 10% and 3.39% respectively compared to 2014 (Ahouissoussi, et al., 2014) while the recycled water is targeted to 25% increase (Ministry of Ecology and Natural Resources of Republic of Azerbaijan, 2010).

2.2.2 Land Use and Projections

In the land use section, the land used for farming, agriculture and industry and the land covered with forests and wetlands are considered. The area covered with wetlands was estimated to be 356.4 thousand hectares in 2017 (Sultanov, Sarukhanova, Kerimov, & Humbatova, 2011) and is assumed to follow the same trend with surface water and reduce by 23% by 2050. The forest areas of the country was reported to be 1213.7 thousand hectares in 2017 (Ministry of Ecology and Natural Resources of Azerbaijan Republic, 2019) which is expected to increase by 6.6% due to the forestation plan of the country. (UNFCC, 2014)

The 2436.2 thousand hectares of the land is used for livestock (Agriculture, forestry and fishing, 2019) which is estimated to increase by almost 41% till 2050 (Bruinsma, 2012). The irrigated land of the country is 1445.8 thousand hectares whereas non-irrigated land is 2054.7 thousand hectares (Agriculture, forestry and fishing, 2019). The irrigation of lands is forecasted to increase by 1.5% while the areas of non-irrigated lands will reduce by 5.4% until 2050 (Bruinsma, 2012).

2.2.3 Food Balances and Projections

The collected data covers food production, the imports, consumption, the exports and the annual forecasts of these values by both production and demand up to 2050. The balance between the total food resources and consumption was verified considering the losses as well (The State Statistical Committee of the Republic of Azerbaijan, 2019).

The production of grains is estimated to increase by 27.4% by 2050 while the demand will only increase 15.7% by this time. The projections on the production of vegetables and fruits are forecasting the increase of 14.4% and 24.9% by 2050 respectively. However, the increase in the demand for both vegetables and fruits is around 30% (Bruinsma, 2012).

The production of meat goods is estimated to increase by almost 90% until 2050 whereas the increase in demand will be 97.14% (Bruinsma, 2012).

2.2.4 Energy Data

In the energy sector, the data on energy demand, production and total annual capacities of different energy sources were collected using "Energy Environment Economy Macro Econometric" (E3ME) and "Open Source Energy Modelling System" (OSeMOSYS) models (Fazekas, Alexandri, & Pollitt, 2017). The data for energy production from OSeMOSYS and demand from E3ME is shown in Table 1 and Table 2 respectively.

Table 1 Energy Production and Total Annual Capacities by Energy Sources in Azerbaijan (2017-2050)

Production [PJ]	2017	2030	2050
Wind	0.98	0.98	0.00
Solar	0.02	0.02	0.00
Hydro	7.19	7.19	6.26
Oil	0.00	0.05	0.00
Gas Total	84.95	94.36	131.77
Gas CC	43.78	61.47	125.66
Gas OC	41.18	32.89	6.11

Table 2 Energy Demand in Different Sectors (2017-2050)

Demand [PJ]	2017	2030	2050
Agriculture	3.53	5.28	8.84
Industry	11.18	13.90	18.22

Residential	26.15	33.30	42.96
Service	18.40	19.64	19.46
Transportation	15.05	20.18	34.71

2.2.5 Climate Data: Emission and Sequestration Factors

In this NEXUS segment, the data collection consisted of constructing the greenhouse gas (GHG) inventory considering both emissions and sequestration factors. The factors are assumed to be constant throughout the study period due to the lack of available data. This assumption considers no improvement in efficiency and sustainability of power generation and agricultural processes, which might not align with the reality of the country's future.

The sequestration factors for forests and grasslands/fallow lands of the country were determined to be 18.6 tCO2eq/ha (Ibrahimov, 2010) and 1.89 tCO2eq/ha (UNFCC, 2014) respectively.

Table 3 Emission Factors in Food Sector

Products	**kgCO2eq/kg product**
Cattle meat	10.93
Sheep meat	19.51
Chicken meat	0.56
Pig meat	2.34
Fresh cow milk	1.17
Fresh goat milk	4.94
Fresh sheep milk	1.44
Paddy rice	2.85
Cereals excluding rice	0.12

The emission factors in power generation were segregated to emissions due to the use of oil or gas. Thus, the emission factor of power generation using gas is estimated to be 0.11 kgCO2eq/kWh which is significantly lower than the emission factor from the oil-based power generation (4.72 kgCO2eq/kWh). (WorldBank, 2012)

Finally, the emission factors for food products which are shown in Table 3 were retrieved from the FAOSTAT database (FAOSTAT, 2016).

3 LIMITATIONS AND ASSUMPTIONS

There are several assumptions and uncertainties in the collected data, which has been used in the SDM population. These assumptions and uncertainties will be stated and evaluated in this section.

Firstly, it is very important to note that the study has been done for only Business as Usual (BaU) scenario.

In the **water sector,** constant volume of the groundwaters and no change in their use was assumed due to BaU scenario. There is a big uncertainty in the industrial use of water resources in Azerbaijan. The industrial use of water has been assumed to increase with the same rate as in the water used for irrigation due to the lack of data. Moreover, the data of water consumption in CCPP was based on the Janub 760 MW plant (Azerenerji Joint Stock Company of the Republic of Azerbaijan, 2009) due to the lack of data on the other plants. Finally, the water consumption was considered to stay constant over the year, which might not be the case if the efficiency in the process would change.

The data collected on the current values of the **land sector** can be considered very reliable since the values were taken from the State Statistical Committee. Nevertheless, some assumptions in the data of this sector were also made. The first factor that can create some uncertainties in the results is the negligence of the influence of the petroleum industry of land quality. Moreover, the use of pesticides in agriculture and their influence on the land were neglected. Finally, the lack of data in the projections of land use (LU) in Azerbaijan caused the trends in the Caucasus and Central Asia LU (Bruinsma, 2012) to be applied to the Azerbaijan case.

The data collected on the **food sector** is the most reliable one compared to other segments of the NEXUS since all the current values (2017 is the baseline year for the model) were taken from State Statistical Committee. Although the data on the food sector is very detailed, the vegetable section doesn't include all the vegetables cultivated in the country. The basic processed food products section also includes only vegetable oils and sugar, which is not the full representation of the processed food industry of the country. The cattle numbers and the agricultural data in the State Statistical Committee are also claimed to retain some uncertainties (UNFCC, 2014).

The demand and production data in the **energy sector** was retrieved from E3ME and OSeMOSYS (Fazekas, Alexandri, & Pollitt, 2017) models respectively. The models underwent the uncertainty check.

The biggest cause of uncertainty in the **climate sector** can be the assumption of the emission and absorption factors to be constant throughout the considered timeframe.

Finally, the waste segment of every sector has been neglected, which might arise some uncertainties in the results of the model. Additionally, the emissions from the construction, residential and transportation sectors were not fully accounted for in the total emissions.

4 RESULTS OF THE SDM

The case studies of SIM4NEXUS project vary from regional to global scale; this work is a national case study of Azerbaijan where results are obtained at a national scale. Thus, this section will include the outputs from the SDM in every NEXUS section at the national scale and the discussion of these results.

4.1 Results for Water Sector

As it was already described in the methodology part of the report, the components considered in the water section of the model are groundwater, surface water, and recycled water on the available water side, and water use for agriculture, irrigation, and industries on the demand side.

Table 4 SDM Results for Available Water Resources

Units (Mm3)	2017	2020	2030	2040	2050
Ground	750	750	750	750	750
Surface	2575	2522.6	2348.0	2173.4	1998.8
Recycled	199.8	204.3	219.0	233.7	248.4
Total	3524.8	3476.9	3317.0	3157.1	2997.2

According to Table 4, the available surface water resources will reduce by 2 percent from 2017 to 2020, whereas after 2020 this value will decrease 3.5 percent every 5 years till 2030. In the next 20 years after 2030, however, the resources of surface water will reduce by almost 4 percent every 5 years. The total reduction of the surface water resources from 2017 to 2050 is calculated to be 22.4 percent.

The situation with water recycling seems to be good for the country since in total the volume of recycled water is forecasted to increase by 24.3 percent from 2017 to 2050 according to the results of the SDM.

Unlike the water recycling values, the situation with total available water in Azerbaijan seems to not have very favorable trends in the considered period. The total available water is forecasted to decrease by 2.3 percent on average for every 5 years from 2020 to 2030. Moreover, the situation is exacerbated in the following 20 years from 2030 as the total available water is forecasted to decrease by 2.5 percent every 5 years. Thus, according to the SDM results the total available water will reduce by almost 15 percent from 2017 to 2050.

Table 5 SDM Results for Water Demand

Units (Mm3)	2017	2020	2030	2040	2050
Irrigation	547.5	552.3	568.5	584.6	600.8
Industrial	185.3	185.9	187.7	189.6	191.4
Domestic	1075.3	1029.3	867.1	691.1	501.2
Total	1808.1	1767.6	1623.4	1465.3	1293.5

Regarding the trends in total water demand (Table 5), the demand in water is forecasted to grow steadily by around 1.2 percent every five years from 2020 to 2050, which will account to total demand growth of 8.1 percent by 2050 compared to 2017.

4.2 Results for Land Sector

The land sector of the model primarily focuses on the different land types of the country, how they are used and the changes in the use of land areas in the future.

The grouping of the results in this section is solely based on whether the subgroup has an increasing or decreasing tendency. Thus, the first batch of results in the land sector includes wetlands, fallow lands, and non-irrigated lands together with potentially irrigated in the future.

Table 6 Results of the SDM for Wetlands, Non-irrigated and Fallow lands

Units (1000ha)	2017	2020	2030	2040	2050
Wetland	356.4	349.1	324.9	300.8	276.6
Non irrigated land	2054.7	2045.0	2012.6	1980.2	1947.7
Fallow land	39.8	39.5	38.5	37.5	36.5

It is retrieved from Table 6 that the wetland areas will decrease by only 2 percent in 3 years from the baseline year. However, after 2020 the increase rate raises up to 3.65 percent for every 5 years period from 2020 to 2040. This percentage decrease in wetland areas gets even higher after 2040, which is forecasted to be 4 and 4.2 percent till 2045 and 2050 respectively. The non-irrigated lands, on the other hand, are forecasted to decrease by 5.2 percent by 2050 compared to 2017.

The next group of results from the land sector of the SDM includes forests, irrigated land areas and lands used for livestock.

Table 7 Results of the SDM for Livestock Lands, Forests and Irrigated Lands

Units (1000ha)	2017	2020	2030	2040	2050
Land for Livestock	2436.2	2524.5	2818.7	3112.9	3407.1
Forests	1213.7	1220.8	1244.6	1268.4	1292.1
Irrigated land	1445.8	1447.7	1454.1	1460.4	1466.8

According to Table 7, the overall expansion of the forests of Azerbaijan is estimated to be 6.46 percent in the whole timeframe of the SDM. On the other hand, if the irrigated lands in 2050 are compared to the baseline year value, the increase of 1.45 percent can be observed from the results.

4.3 Results for Food Sector

The results of this sector are only discussed in the climate section of the report to analyze their effect on the GHGs.

4.4 Results for Energy Sector

It should be mentioned that due to lack of input data, which is caused by the confidentiality of these data, for the whole energy sector of Azerbaijan only electricity production was used as an input for the model. Thus, the results of the SDM for the production side of this section only includes electricity production. However, in the results on the energy consumption side, coverage of the total scene was attempted.

4.4.1 Electricity Production

In electricity production section, the results of the electricity production from oil, closed cycle (Gas CC) and open cycle (Gas OC) gas sources, hydropower, wind, and solar energy are included.

Table 8 Results of the SDM for Fossil Fuel Based Electricity Production

Units (GWh)	2017	2020	2030	2040	2050
Oil	0.00	0.00	1.08	53.16	0.00
Gas OC	953.19	1018.4	761.29	70.22	141.36
Gas CC	1013.3	1013.3	1423.0	2473.9	2908.9

As can be seen from Table 8, Gas CC is the dominating method of electricity production throughout the years and the production increases every year. In 2050 the production of electricity from gas CC is forecasted to reach its' maximum by reaching 2908.91 GWh.

Table 9 Results of the SDM for Renewable Electricity Generation

Units (GWh)	2017	2020	2030	2040	2050
Hydro	166.4	166.4	166.4	163.2	144.98
Wind	22.73	22.73	22.62	0.00	0.00
Solar	0.44	0.44	0.44	0.00	0.00

Additional to the fossil fuel-based electricity generation, production of electricity from renewable energy sources are also retrieved from E3ME and OSeMOSYS, which is illustrated in Table 9. The production of electricity from wind and solar is not provided by the model after 2030. The changes in electricity generation from renewable sources are not forecasted to increase considering the BaU scenario and the production is estimated to reduce slightly due to the domination of gas electricity production.

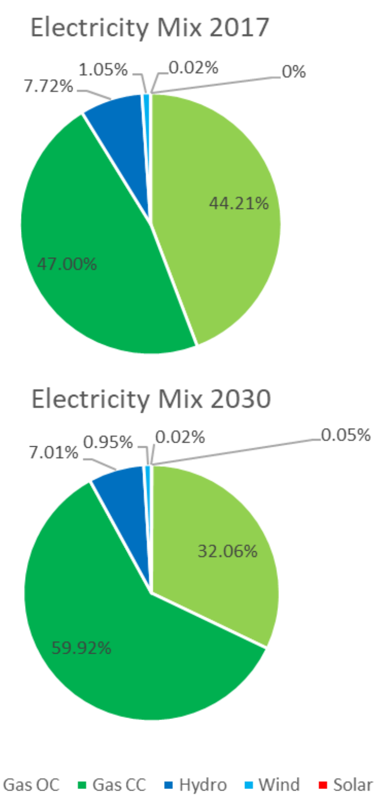

Figure 2 Energy Mix of Azerbaijan (2017, 2030)

Figure 2 illustrates the differences in the electricity mix of the country in 2017 and 2030. According to these pie charts, the oil-based electricity production will enter the mix in 2030 by 0.05 percent. Moreover, the share of gas-based electricity generation changes but still holds the biggest share in the mix. The Gas OC generation reduces its' share by 12.15 percent whereas Gas CC increases by 12.92 percent from 2017 to 2030.

4.4.2 Energy Demand

This section covers residential, agricultural, and industrial energy demand as well as demand in transportation and services.

Table 10 Results of the SDM for Energy Demand

Units (Ktoe)	2017	2020	2030	2040	2050
Residential	52.06	53.18	66.28	75.53	85.51
Services	36.61	36.92	39.09	38.64	38.73
Agriculture	7.03	8.08	10.52	15.21	17.60
Industry	22.25	22.71	27.67	31.69	36.26
Transport	29.95	31.47	40.17	52.49	69.10
Total	147.9	152.4	183.7	213.6	247.2

The results of the SDM for energy demand in every considered area and forecasts of these values are summarized in Table 10.

The highest increase in the energy demand is projected to be observed in irrigation and agriculture as the demand here increases from 7.03 Ktoe to 17.60 Ktoe, which is a rise of around 60 percent from 2017 to 2050.

The demand in transportation comes second as here an increase of 56.7 percent is estimated. On the other hand, together with having the lowest overall increase of 5.5 percent from baseline year to 2050, energy demand in services is also the only area where a decrease in demand is forecasted in the intermediate period. Thus, the reduction of 1.2 percent in the energy demand in services is projected to occur from 2030 to 2040.

4.5 Results for Climate

The final section of the SDM results is the projections on the GHG emissions and sequestration from 2017 to 2050. The GHG results include the emissions from the energy and food sectors whereas sequestration of these gases includes absorption of GHGs by forests and fallow lands.

4.5.1 GHG Emissions

It can be noted from Table 11 that there is a general increasing trend in the total GHG emissions throughout the considered period.

Table 11 Results of the SDM for GHG emissions

Units tCO2eq	2017	2020	2030	2040	2050
Energy	219359.57	226633.09	248765.09	534770.59	340251.96
Food	483.82	483.82	582.90	582.90	632.10
Total	219843.40	227116.92	249347.99	535353.49	340884.05

Although the emissions from energy production are estimated to increase by 35.5 percent in 2050 compared to the baseline year, the emissions from this sector significantly reduce by 57.2 percent from 2040 to 2050. The increase in the emissions from the food sector is forecasted to be 17 percent from 2020 to 2030, 7.8 percent from 2040 to 2050. In total, food production is projected to emit 23.5 percent more GHGs in 2050 compared to 2017.

4.5.2 GHG Sequestration

Sequestration by forests and wetlands will increase by 6.1 percent but sequestration by fallow lands will decrease by 9 percent from 2017 to 2050. The total sequestration, however, will increase by 5.7 percent in the timeframe of the SDM.

5 COMPARATIVE ANALYSIS OF GHG EMISSIONS AND SEQUESTRATION

It is important to compare the emissions to sequestered amount to understand the balance of emissions and their effect on the climate of the country.

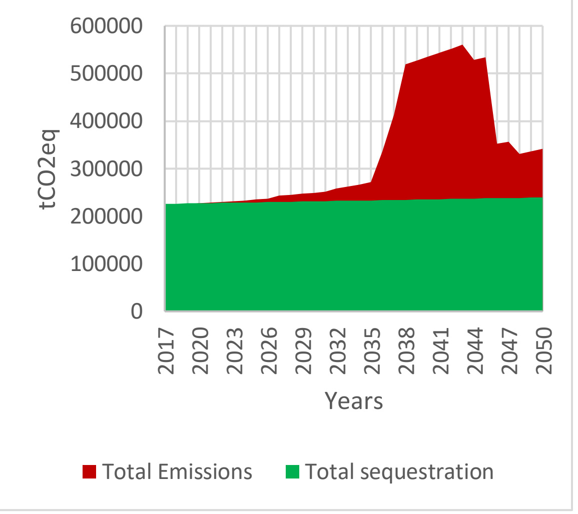

Figure 3 Comparison of GHG Emissions and Sequestration

The results for total GHG emissions and total sequestered amount are plotted in Figure 3, which projects the excess of the emissions from 2020 onwards. The gap between the emissions and sequestration is forecasted to steadily increase until 2035 after which the gap starts to drastically increase. Thus, the change in the gap reaches 86.5 percent in only 4 years after 2035. The peak of the gap will be reached in 2043 when 323.93 ktCO2eq GHGs emissions will be left non-sequestered. To sum up, despite the gap between emissions and sequestration reducing from 2044 onwards, emissions are forecasted to always exceed the sequestered amount.

6 SOLUTIONS AND RECOMMENDATIONS

The aim of this section of the report will be to describe the possible solutions and provide some recommendations to reduce the GHGs and improve the sustainability status of the country.

6.1 Energy Sector

- Acquiring the progressive emission monitoring systems
- Efficiency improvement in energy technologies
- Prevention of petroleum/gas line leakages
- Improved management of HC discharge
- Policy changes supporting the positive framework for RES to enter the market and

have a share in the energy mix of the country.
- Creating an independent entity for distribution grid or creating a legal basis/tariffs for grid utilization by RES
- Incentivizing the installations of renewable energy systems
- Liberalizing the energy market
- Open RES market to private investments
- Reform the pollution permit system and reconsider the fines applied
- Improvement of GHG metering

6.2 Agriculture Sector

- Education of farmers and raising their awareness of sustainable farming and agriculture techniques
- Policymaking push in increasing the incentives for farmers and providing additional funds for aligning with the sustainable techniques
- Governmental investment in R&D of this sector

7 CONCLUSIONS

In an attempt to fill the gap in in the research regarding the holistic view of Azerbaijan's economy and the studies regarding the transition of the country to more sustainable development, this work aimed at investigating Azerbaijan's transition to a low carbon pattern by determining the links between the NEXUS of water, land, food, energy and climate and analyses of the dynamics between them. Additionally, the work had the objective of coming up with solutions and recommendations for effective policymaking in Azerbaijan to push the country towards more sustainable development.

Hence, the work has successfully analyzed every sector of the NEXUS by investigating the dynamics in these sectors and their effect on the climate of the country taking 2017 as a baseline year and projecting these dynamics to 2050. Recommendations and solutions in the energy and agricultural sectors, which were shown to be the biggest GHG emitters according to the SDM results, as well as suggestions regarding the pollution permits and emission metering were proposed in this work to provide policy insights to policymakers.

Although several challenges had been faced during the work especially in the data collection and post-processing of the results of the SDM, they were successfully overcome and the results for every sector were obtained.

Although there were some favorable results of the work such as an increase in water recycling, forecasts of the forest expansion, reduction of the production of some meat types, increase in vegetable consumption, the final comparative analysis of GHG emission and sequestration showed an excess of emission in the future.

To conclude, considering that this study has been done for a Business as Usual scenario, future studies could include several cases and scenarios with assumptions of policy changes and changes in the country's targets regarding renewables. Moreover, studies on the financial needs for the suggested solutions and recommendations could be carried out as future studies.

7.1 Future Studies

To summarize, it is also important to propose future studies that can follow this work to further explore the topic. Thus, this section will include suggestions for future studies regarding the topic.

Firstly, considering that this study has been done for a Business as Usual scenario only, future studies could include several cases and scenarios such as:

- Higher Renewable Energy Sources Penetration Scenario
- Permaculture Designed Farming/Agriculture Scenario

Moreover, analysis of how an increase in pollution fines and having more precise emission metering systems would change GHG emissions can be done.

Finally, after having the analysis of several scenarios, the financial and technological needs to change towards a low-carbon economy should be assessed to investigate the feasibility of these changes considering the current economic capacity of the country.

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