THE RELATIONSHIP BETWEEN FOOD SUPPLY SECURITY AND ENERGY SECURITY WITH THE USE OF BIOENERGY SOURCES: TURKEY PROJECTION WITH SYSTEM DYNAMICS APPROACH

ÇELIK, M.

Faculty of Agriculture, Dr. Dicle University, Sur, Diyarbakir, Turkey
(e-mail: muhammed.celik@dicle.edu.tr; phone: +90-541-395-6848)

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Abstract. Bioenergy is an indigenous and renewable energy source derived from organic matter. Typically, organic waste and agricultural products are used as primary input sources in its production. In this study, the impact of bioenergy production on food security and energy security in Turkey until the year 2050, depending on resource usage, was modeled using a system dynamics approach. Various scenario tests were conducted using the created system dynamics model to observe how energy security and food security are affected by different variables and resource usage in Turkey. As a result, using agricultural production for bioenergy is not a sustainable policy. Besides significantly affecting food security negatively, its potential to positively affect energy security is quite limited. Consequently, it may lead to competition between food production and energy production. Therefore, considering the increasing population and food demand trends in Turkey, a bioenergy policy should be developed that does not create competition between food-oriented agricultural production and energy-oriented agricultural production, focusing solely on using waste as a resource.
Keywords: *food supply security, energy security, bioenergy, system dynamics, Turkey*

Introduction

In the current century, humanity is facing interconnected and complex issues of food security, energy security, and climate change globally. Additionally, the increasing population and the consequent rise in demand underscore the importance of sustainably managing natural resources to ensure universal access to healthy food and energy (Scott et al., 2015; Mohtar and Lawford, 2016; Amorima et al., 2018; Tugyan, 2015).

Bioenergy, which holds a significant place among renewable energy sources, is a type of energy derived from organic matter, including agricultural and forest products, municipal waste, as well as both living and non-living biological materials, and animal and industrial waste, through the conversion of solar energy into chemical energy via photosynthesis (Sözen et al., 2017). Biomass, as a term, refers to all organic materials, including plants grown on land and in water, forests, animal waste, all types of herbaceous and woody plants, as well as organic wastes from industries and municipalities. These biomass resources are processed through various physical, chemical, and biological processes to convert them into solid, liquid, and gaseous bioenergy with standardized commercial properties. Biomass resources used in bioenergy production consist of all types of living biological materials, primarily including animal, plant, agricultural algae, and organic industrial wastes (Sing et al., 2021). Bio-waste management is a highly emphasized issue in both developed and developing countries. Ensuring the sustainability of the circular economy and bioeconomy is crucial in terms of resource efficiency goals (Jain, 2022).

As a renewable energy source, bioenergy serves as an important alternative to reduce dependence on fossil fuels and mitigate the adverse effects of global warming. Its

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potential to reduce dependence on fossil fuels has led to increased interest in bioenergy, especially in importer countries with high fossil fuels dependency. Furthermore, bioenergy facilitates substitution between two different commodities, such as food and energy (Gunatilake et al., 2014; Alston et al., 2009). The United Nations prioritizes food security and energy security in its 2030 agenda, with bioenergy playing a significant role in achieving both goals. Global analyses, interpretations, and cartoons that blame bioenergy for food shortages in certain regions may be made with good intentions. However, they mislead the public and policymakers by obscuring the real reasons behind food security issues and overlooking the opportunities for bioenergy to contribute to solutions (Kline et al., 2017).

Energy is central to development and ensuring food security in modern life. Discussions since 2015 and the recognition of the central role of energy under the United Nations' "Sustainable Energy for All Initiative" have aimed at providing universal energy access (Maltsoglou et al., 2015). Food and energy are two fundamental elements for sustaining human life and fostering continuous development (Bleischwitz et al., 2018).

Food security is a complex and multi-dimensional issue encompassing the availability, access, utilization, and stability of food. Global food crises and hunger issues in various parts of the world highlight the significance of food security. International organizations working in this field, along with local governments, implement various policies. Despite its positive effects on rural development, climate change, and energy security, bioenergy has a complex relationship with food security (Kline et al., 2017; Alsaleh et al., 2021; Maltsoglou et al., 2015). From this perspective, expanding bioenergy supply to mitigate the effects of climate change is perceived as a new and poorly understood threat to food security (Ahmed et al.,2021).

Bioenergy has the potential to affect food security in two different ways. Firstly, the expansion of energy-oriented agriculture leads to competition between energy-oriented and food-oriented agricultural production. The conversion of agricultural land used for food production to energy-oriented agricultural production negatively impacts food supply (Bureaua et al., 2017; Cunha Diasa et al., 2021; Hasegawal et al., 2020). In 2006, in the European Union, a significant biodiesel producer, the area allocated to oilseeds for biodiesel production approached about 22% of the total oilseed production area, compared to around 12% at the end of 2004. Considering this trend, the pressure of energy-oriented production on food supply becomes more evident (Steenbilik, 2008). A similar situation exists for significant bioenergy producers like the United States and Brazil, where energy-oriented agricultural production suppresses food production. This phenomenon is also observed in countries with high energy demand like China, where bioenergy-oriented agricultural production competes with food production. An increase in bioenergy supply negatively affects food security in terms of availability, accessibility, utilization, and stability. Moreover, the rise in population adversely impacts both bioenergy and food security (Subramaniam, 2023).

The use of food products for bioenergy production leads to a contraction in this area. It is observed that the use of corn for energy purposes causes a reduction in the supply of corn for food purposes by 116.5 million tons. Considering that one person's annual calorie requirement is 800,000 kilocalories, it is calculated that when 116.5 million tons of corn is utilized for food supply, it is equivalent to meeting the calorie needs of 495 million people for one year (Hatunoğlu, 2010).

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Secondly, bioenergy affects food security in terms of food prices. It has been noted that the redirection of agricultural land used for food production towards energy-oriented agricultural production will lead to a contraction in food supply. This situation will result in an increase in food prices (Börzel, 2016; Vassile and et al., 2016). It has been observed that the use of food for energy purposes negatively affects food supply security, leading to a contraction in food supply. This contraction has been concretely observed with a 64% increase in prices in the FAO Food Price Index from 2002 to 2008.

Energy plays a crucial role in influencing all production activities of a country, directly impacting its growth and development (Maltsoglou et al., 2015). Especially for developing countries like Turkey, which are heavily dependent on energy imports, economic stability is among the leading reasons for trade deficits and budget deficits (Sözen et al., 2017). The concentration of conventional energy sources in certain regions globally has made ensuring energy supply security one of the most important priorities for many countries. The vital importance of energy security has led to a significant increase in research and development (R&D) efforts related to domestic production and alternative energy sources.

Examination of energy security definitions and indices reveals the positive impact of domestic production on energy security. Therefore, bioenergy, being renewable and produced from local sources, is an important factor in terms of energy security. An increase in bioenergy supply will increase the proportion of domestic production within the overall energy supply. An increase in domestic energy supply is also expected to have a positive impact on energy security.

The Republic of Turkey has made significant progress in economic sectors in recent years, leading to an increase in energy demand. It meets 75% of its energy needs through imports (Acaravcı and Yıldız, 2018), almost all of which come from fossil fuels (Ministry of Energy and Natural Resources, 2021). Considering the negative impact of this situation on environmental security and international risks, it is necessary to increase domestic resource diversity in Turkey. In this context, bioenergy is an important source for Turkey as an agricultural country. However, increasing domestic and renewable resource diversity also poses different risks.

Considering the aforementioned points, it is clear that bioenergy and the increasing demand generated by the growing population will have an impact on food supply in Turkey (Canan and Ceyhan, 2017). However, it is necessary to control this impact and achieve a successful synergy between bioenergy and food security. Therefore, this study aims to examine the impact of policies aimed at increasing bioenergy supply as a domestic and renewable source in Turkey on energy and food security, as well as the mutual relationship between these resources in terms of security. It is vital to develop sustainable solutions that address the interconnected aspects of land degradation, food demand, access to healthy food, population growth, and climate change to ensure energy and food security simultaneously (Garcia Lopez et al., 2023).

Materials and methods

System dynamics is used to describe and predict the interactions or relationships among multiple components of a phenomenon that ensure its continuity as a system. It focuses on understanding the direction and degree of interaction among components within the system and how the components, as well as the system as a whole, develop over time.

In the field of social sciences, the system dynamics modeling approach is increasingly being used as a tool for advanced data analysis of increasingly complex relationships. It is gaining attention as a highly useful tool in theory development, testing, and policy-making processes.

Rational and systematic thinking is necessary for solving comprehensive and complex problems encountered or newly realized in social life. System dynamics modeling and simulation methods have emerged as significant alternatives in recent years for solving problems formed by comprehensive and complex components.

In this study, a projection model for Turkey's energy-food-population future was created using the system dynamics method and the Stella software package. Firstly, comprehensive theoretical knowledge was obtained regarding the energy system, food supply system, and the population subsystem added to this model, as well as the bioenergy subsystem. This facilitated the depiction of the direction, level, and condition of the relationship between variables comprising each subsystem in the model. Then, the relationship status, direction, and level between these subsystems were defined in the model to create the Turkey Energy-Food future projection model using Stella system diagrams.

The main theme of our study is to examine the impact of increased use of bioenergy resources on food security and energy security in Turkey. For this purpose, variables for energy security and food security were defined in the energy-food-population projection model. Energy security and food security have been approached from various dimensions in the literature. Considering the dimension of resource utilization in our study, demand and supply balances for energy security and food security were modeled adopting a self-sufficiency approach based on the data set and future projection system.

Energy security module

The concept of energy security varies from country to country and region to region. For countries in a supplier position, ensuring the continuity of production is the most important aspect of energy security, while for a country dependent on imports, meeting demand and ensuring the supply chain are crucial. Additionally, for a transit country along an energy route, ensuring transit security forms the main axis of energy security. Concepts such as environmental sustainability, price stability, and energy efficiency further expand the scope (Ang et al., 2015; Radovanović et al., 2017; Azzuni and Breyer, 2020; Narula and Reddy, 2016; Karagol et al., 2017).

Due to its resource diversity and multidimensional variables, measuring energy security is quite challenging. There are various methods and approaches in the literature for measuring energy security. Considering the main focus of our study, we have focused on some of the most commonly used measurements, and our system dynamics model incorporates the measurement of a few of them.

Energy Dependency Ratio: This ratio is based on the proportion of energy imports in the total energy used. It indicates how much of a country's energy usage (in terms of TEP) is met through imports (Erdal, 2011). In our study, the calculation of the proportion of total imported energy within total energy consumption is included. This index is used in the model as:

$$\text{Energy Dependency Ratio} = \text{Energy Imports} / \text{Energy Consumption}$$

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An increase in the energy dependency ratio signifies an unfavorable situation for energy security because it indicates a rise in the amount of imported energy within total energy consumption, which is undesirable.

Domestic Production Ratio: This ratio indicates the proportion of energy produced within the country's borders in the total energy consumed (in TEP). This index is expressed as:

Domestic Production Ratio = Domestic Energy Production / Total Energy Consumption

An increase in the domestic production ratio is considered a positive development for energy security, contrary to the energy dependency ratio. Therefore, an increase in domestically produced energy within total energy consumption is beneficial for energy security.

Food security module

Food security is a complex concept defined by considering accessibility, availability, quality, and safety dimensions together. The weights of each dimension in terms of food security are both different and can vary from country to country and region to region.

According to the Food and Agriculture Organization (FAO) of the United Nations, food security is defined as "all people having access, both economically and physically, to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active and healthy life". As understood from this definition, food security is a complex concept with an integrated function.

Turkey ranks first in agricultural production among EU countries and 10th globally, positioning itself as a global food supplier. With its current state, it has the capacity to be self-sufficient in food supply. Considering the complex and integrated structure of food security (Bala et al., 2014), a perspective based on the individual living in the country was adopted in modeling. Therefore, in our model, the concept of food security refers to having enough food supply (in tons) for the entire population, with each individual having enough food available. Upon reviewing the literature, it is observed that in the overwhelming majority of food security indices, food supply security has the greatest weight within food security. Therefore, in our study, the food supply dimension for food security was considered and utilized in the model.

As the main focus of our study is the potential of bioenergy as a source of competition with land for local food supply, our system dynamics model was constructed by considering the amount of domestically produced agricultural food, free from imports, with the capacity to meet the country's population. One of the main objectives of our model is to examine how changes in bioenergy resource utilization may affect Turkey's self-sufficiency in food supply. Therefore, in our model:

Food Security: Food Quantity Free from Losses / Food Demand

This formula represents the amount of food free from losses produced in Turkey being able to meet the food demand of the entire population. An increase in the Food Security ratio is considered a positive development for food security. Therefore, an increase in this ratio indicates an improvement in Turkey's self-sufficiency in food supply.

Raw data were obtained from the official website of the Republic of Turkey Ministry of Agriculture and Forestry and TURKSTAT and used in the model. Proportional data were calculated by the author. System dynamics is a method aimed at modeling

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complex systems. In this study, the aim was to observe the impact of bioenergy supply on Turkey's food supply security through a forward-looking projection. For this purpose, the interconnected and complex system of energy, bioenergy, population, food supply, and food demand was modeled. These subsystems influence each other. The continuously increasing energy demand and the adverse effects of global warming drive the need for alternative energy sources such as bioenergy. The rise in bioenergy demand increases the demand for agricultural production, which is one of the sources of bioenergy. Consequently, a portion of agricultural production intended for food may shift towards energy-focused agriculture. When considered together with the continuously growing population, this situation negatively impacts food supply security. In this study, these complex relationships, along with other variables, were modeled and simulated, as shown in *Figure 1*.

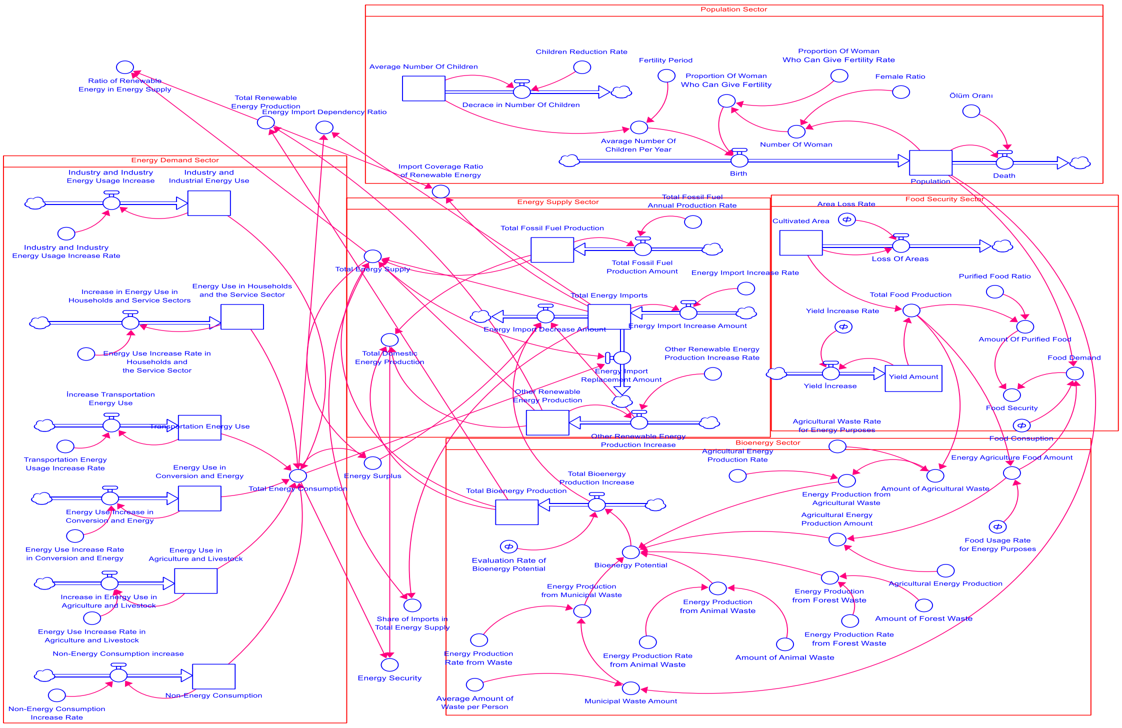

Figure 1. *Stella diagram of Turkey' s bioenergy-energy security-food security future projection model*

The values of stock, flow and converters used for bioenergy-energy security-food security future projection in the model and the defined mathematical equations that form the framework for the operation of the model are defined as follows:

Average_Number_Of_Children (t) = Average_Number_Of_Children (t - dt) + (- Decrace_in_Number_Of_Children) * dt
Population (t) = Population (t - dt) + (Birth - Death) * dt
Birth = Avarage_Number_Of_Children_Per_Year * Proportion_Of_Woman_Who_Can_Give_Fertility
Death = Ölüm_Oranı * Population

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Decrace_in_Number_Of_Children = Children_Reduction_Rate * Average_Number_Of_Children
Avarage_Number_Of_Children_Per_Year = Average_Number_Of_Children / Fertility_Period
Number_Of_Woman = Population * Female_Ratio
Proportion_Of_Woman_Who_Can_Give_Fertility = Number_Of_Woman * Proportion_Of_Woman_Who_Can_Give_Fertility_Rate
Other_Renewable_Energy_Production (t) = Other_Renewable_Energy_Production (t - dt) + (Other_Renewable_Energy_Production_Increase) * dt
Total_Energy_Imports (t) = Total_Energy_Imports (t - dt) + (Energy_Import_Increase_Amount - Energy_Import_Decrease_Amount - Energy_Import_Replacement_Amount) * dt
Total_Fossil_Fuel_Production (t) = Total_Fossil_Fuel_Production (t - dt) + (Total_Fossil_Fuel_Production_Amount) * dt
Energy_Import_Replacement_Amount = IF (Total_Energy_Consumption < = Total_Energy_Supply)THEN(0)ELSE(Total_Energy_Supply-Total_Energy_Consumption)
Total_Fossil_Fuel_Production_Amount = Total_Fossil_Fuel_Production * Total_Fossil_Fuel_Annual_Production_Rate
Other_Renewable_Energy_Production_Increase = Other_Renewable_Energy_Production * Other_Renewable_Energy_Production_Increase_Rate
Energy_Import_Dependency_Ratio = Total_Energy_Imports/Total_Energy_Consumption
Import_Coverage_Ratio_of_Renewable_Energy = Total_Renewable_Energy_Production/Total_Energy_Imports
Total_Renewable_Energy_Production = Other_Renewable_Energy_Production + Total_Bioenergy_Production
Yield_Amount (t) = Yield_Amount (t - dt) + (Yield_İncrease) * dt
Energy_Import_Increase_Amount = Total_Energy_Imports * Energy_Import_Increase_Rate
Cultivated_Area (t) = Cultivated_Area (t - dt) + (- Loss_Of_Areas) * dt
Yield_İncrease = Yield_İncrease_Rate * Yield_Amount
Loss_Of_Areas = Cultivated_Area * Area_Loss_Rate
Total_Food_Production = Cultivated_Area * Yield_Amount
Amount_Of_Purified_Food = Total_Food_Production * Purified_Food_Ratio
Total_Bioenergy_Production (t) = Total_Bioenergy_Production (t - dt) + (Total_Bioenergy_Production_Increase) * dt
Total_Bioenergy_Production_Increase = Bioenergy_Potential * Evaluation_Rate_of_Bioenergy_Potential
Agricultural_Energy_Production_Amount = Agricultural_Energy_Production * Energy_Agriculture_Food_Amount
Amount_of_Agricultural_Waste = Total_Food_Production * Agricultural_Waste_Rate_for_Energy_Purposes
Bioenergy_Potential = Energy_Production_from_Municipal_Waste + Energy_Production_from_Animal_Waste + Energy_Production_from_Agricultural_Waste + Energy_Production_from_Forest_Waste + Agricultural_Energy_Production_Amount
Energy_Agriculture_Food_Amount = Total_Food_Production * Food_Usage_Rate_for_Energy_Purposes

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Energy_Production_from_Agricultural_Waste = Amount_of_Agricultural_Waste * Agricultural_Energy_Production_Rate
Energy_Production_from_Animal_Waste = Energy_Production_Rate_from_Animal_Waste * Amount_of_Animal_Waste
Energy_Production_from_Forest_Waste = Energy_Production_Rate_from_Forest_Waste * Amount_of_Forest_Waste
Energy_Production_from_Municipal_Waste = Municipal_Waste_Amount * Energy_Production_Rate_from_Waste
Energy_Security = Total_Domestic_Energy_Production/Total_Energy_Consumption
Energy_Surplus = Total_Energy_Supply-Total_Energy_Consumption
Food_Demand = (Food_Consuption * Population) + Energy_Agriculture_Food_Amount
Food_Security = Amount_Of_Purified_Food/Food_Demand
Ratio_of_Renewable_Energy_in_Energy_Supply = Total_Renewable_Energy_Production/Total_Energy_Supply
Share_of_Imports_in_Total_Energy_Supply = Total_Energy_Imports/Total_Energy_Supply
Municipal_Waste_Amount = Population* Average_Amount_of_Waste_Per_Captain
Total_Domestic_Energy_Production = Total_Fossil_Fuel_Production + Other_Renewable_Energy_Production + Total_Bioenergy_Production
Total_Energy_Consumption = Industry_and_Industrial_Energy_Use + Energy_Use_in_Households_and_the_Service_Sector + Transportation_Energy_Use + Energy_Use_in_Conversion_and_Energy + Energy_Use_in_Agriculture_and_Livestock + “Non-Energy_Consumption”
Total_Energy_Supply = Total_Fossil_Fuel_Production + Total_Energy_Imports + Other_Renewable_Energy_Production + Total_Bioenergy_Production
Energy_Use_in_Agriculture_and_Livestock (t) = Energy_Use_in_Agriculture_and_Livestock (t - dt) + (Increase_in_Energy_Use_in_Agriculture_and_Livestock) * dt
Energy_Use_in_Conversion_and_Energy (t) = Energy_Use_in_Conversion_and_Energy (t - dt) + (Energy_Use_Increase_in_Conversion_and_Energy) * dt
Energy_Use_in_Households_and_the_Service_Sector (t) = Energy_Use_in_Households_and_the_Service_Sector (t - dt) + (Increase_in_Energy_Use_in_Households_and_Service_Sectors) * dt
Industry_and_Industrial_Energy_Use (t) = Industry_and_Industrial_Energy_Use (t - dt) + (Industry_and_Industry_Energy_Usage_Increase) * dt
“Non-Energy_Consumption”(t) = “Non-Energy_Consumption”(t - dt) + (“Non-Energy_Consumption_increase”) * dt
Transportation_Energy_Use (t) = Transportation_Energy_Use (t - dt) + (Increase_Transportation_Energy_Use) * dt
Energy_Use_Increase_in_Conversion_and_Energy = Energy_Use_Increase_Rate_in_Conversion_and_Energy * Energy_Use_in_Conversion_and_Energy
Increase_in_Energy_Use_in_Agriculture_and_Livestock = Energy_Use_Increase_Rate_in_Agriculture_and_Livestock * Energy_Use_in_Agriculture_and_Livestock
Increase_in_Energy_Use_in_Households_and_Service_Sectors = Energy_Use_Increase_Rate_in_Households_and_the_Service_Sector * Energy_Use_in_Households_and_the_Service_Sector
Increase_Transportation_Energy_Use = Transportation_Energy_Use * Transportation_Energy_Usage_Increase_Rate
Industry_and_Industry_Energy_Usage_Increase = Industry_and_Industrial_Energy_Use * Industry_and_Industry_Energy_Usage_Increase_Rate

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“Non-Energy_Consumption_increase” = “Non-Energy_Consumption_Increase_Rate” * “Non-Energy_Consumption”

Stella software program was used for the calibration of the model (*Table 1*). The Powell method was applied which is the fastest and most accurate one. The values obtained as a result of calibration are the basic values used in simulations. In the validation of system dynamics models, it is first necessary to test the validity of the constructed model structure and then test its behavioral accuracy (Barlas, 1996). Therefore, in this study, the structural validity of the model was calibrated through optimization. It was also observed through experiments that the model successfully demonstrated the behaviors exhibited by Turkey’s real system.

Scenario trial and findings

In this section, various scenario trials were conducted on the model created to simulate the impact of bioenergy resource utilization on energy security and food security in the case of Turkey. Scenario selection considered variables such as the designated resource utilization for bioenergy production, agricultural yield affecting both bioenergy source and food supply, dietary habits, and the continuation of the current status quo. Scenarios were formulated based on these considerations, and various findings were obtained through these scenario trials. The scenario trials applied in the model are listed in *Table 2*.

Table 1. *Calibration results*

Method	Maxiter	init_step	Tolerance
Powell	5000	1	0.00001

Payoff:	Payoff		
Action	Minimize		
Kind	Calibration		
Element	Loss of areas	Total bioenergy production increase	Yield increase
Weight	Auto	Auto	Auto
Comparison variable	Loss of areas	Total bioenergy production increase	Yield increase
Comparison run	Run 1	Run 1	Run 1
Comparison type	Squared error	Squared error	Squared error
Comparison tolerance	0	0	0

Parameter	Area loss rate	Yield increase rate	Evaluation rate of bioenergy potential
min_value	0	0	0
max_value	1	1	1
Scaling	1	1	1

	Area loss rate	Yield increase rate	Evaluation rate of bioenergy potential	Payoff
Starting at	0.004537104543	0	0.088297160383	
After 74 runs	0.00448658053642	0(min)	0.0872494027194	0.0000270680582322

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Table 2. *Applied scenarios*

Scenarios number	Scenarios
Scenario 1	This scenario describes the continuation of the current situation where surplus energy supply is substituted for imported energy
Scenario 2	5% of agricultural production was used for energy purposes, and bioenergy production was increased by 25% through increased investments in bioenergy. Surplus energy supply substituted imported energy
Scenario 3	Agricultural yield was increased by 1.5% annually, with 5% of agricultural production used for energy purposes. Bioenergy production was increased by 25% through augmented investments in bioenergy. Surplus energy supply substituted for imported energy
Scenario 4	Agricultural yield was increased by 1.5% annually, and by changing dietary habits, per capita annual food consumption increased by 3%. 5% of agricultural production was used for energy purposes, and bioenergy production was increased by 25% through increased investments. Surplus energy supply substituted for imported energy
Scenario 5	Annual agricultural yield was increased by 1.5%, and by conserving agricultural lands, losses were reduced by 0.5%. 5% of agricultural production was used for energy purposes, and bioenergy production was increased by 25% through increased investments. Surplus energy supply substituted for imported energy

When examining *Figure 2,* it is observed that according to the first scenario, Turkey maintains its ability to meet the food demand of its population until 2050. However, around 2045, it is seen that the domestic supply-demand balance is disrupted, and a portion of the exported production needs to be used for domestic consumption. On the other hand, in Scenario 2, it is observed that the use of a portion of the production for energy purposes disrupts the supply-demand balance earlier, around 2040. In the other three scenarios, due to the increase in agricultural yield and the conservation of agricultural lands, Turkey's food supply-demand balance is positively influenced to a considerable extent.

Upon examining the scenario comparisons in *Figure 3,* it is observed that the 3rd and 5th scenarios are the most suitable for preserving food security. It is noted that the 2nd scenario, which involves agricultural production for energy purposes, has a significantly adverse impact on food security.

When examining *Figure 4,* it is observed that increasing bioenergy investments and thus enhancing the utilization rate of the potential lead to an increase in bioenergy supply.

When examining *Figure 5,* it is observed that the capacity of bioenergy to affect Turkey's security is quite low.

Discussion and conclusions

Within Turkey's energy diversity, the bioenergy supply is at a considerably low level. Therefore, its ability to affect energy security is very low. Findings obtained through the system dynamics model created for the Turkey case and scenarios tested on

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this model regarding the interaction between energy security and food security based on bioenergy resource utilization are outlined below:

If current policies continue, energy demand in Turkey will continue to rise, leading to continued energy imports. However, there will be a decrease in the proportion of imported energy in the total energy supply. Additionally, although there is not a significant increase in bioenergy supply, the share of renewable energy sources in energy supply is continuously increasing.

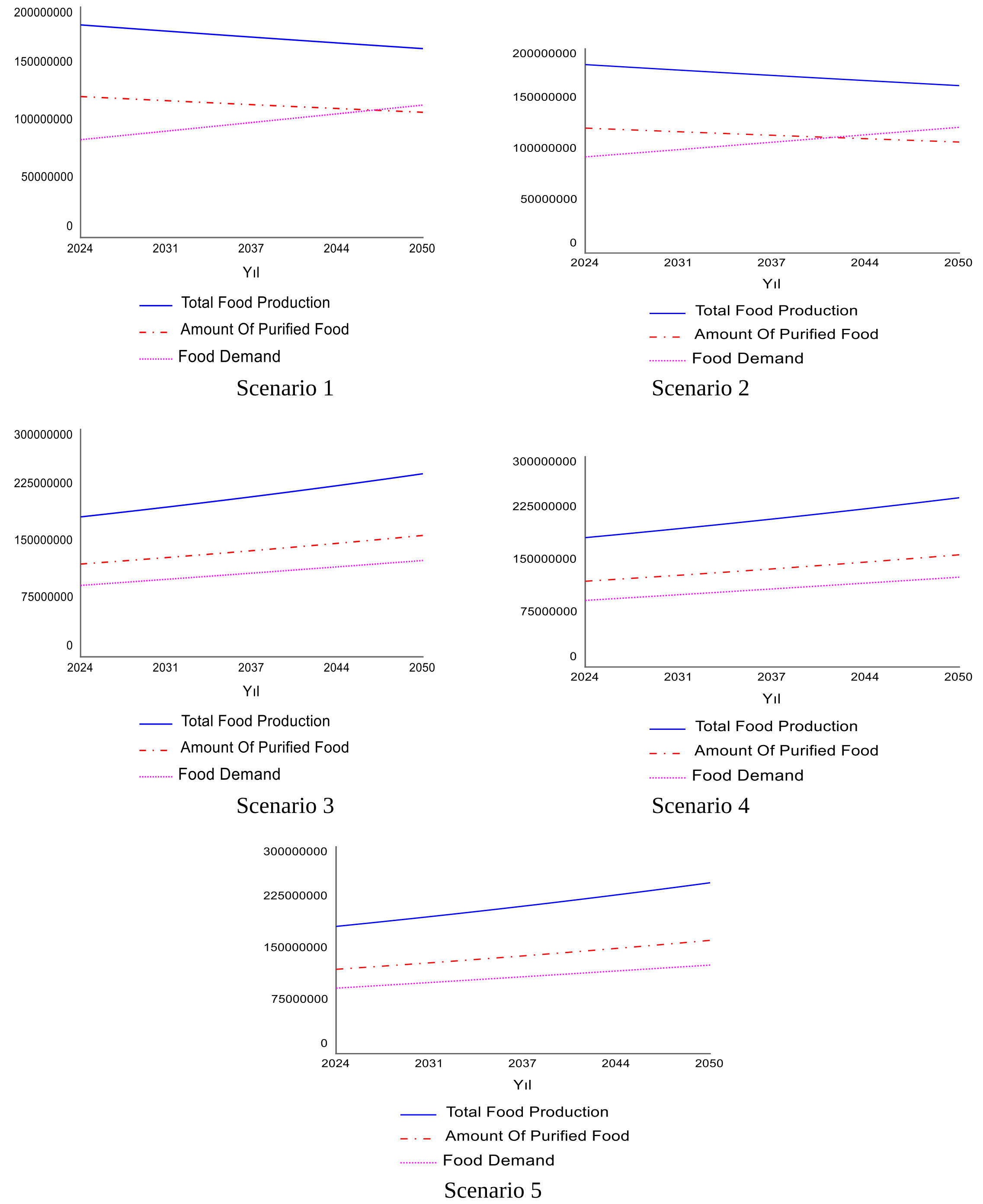

Figure 2. *Food suply and food demand*

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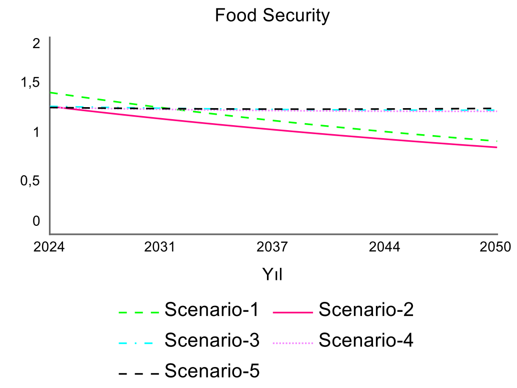

Figure 3. *Turkey's food security projection*

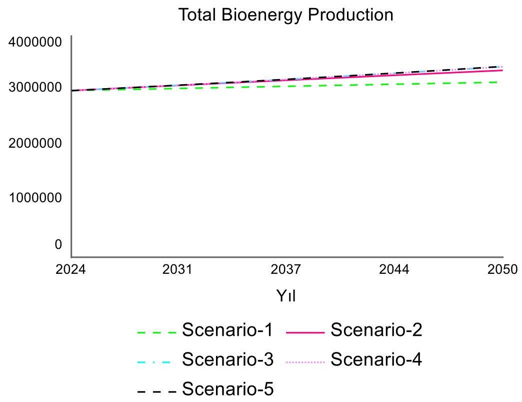

Figure 4. *Turkey's food supply security projection*

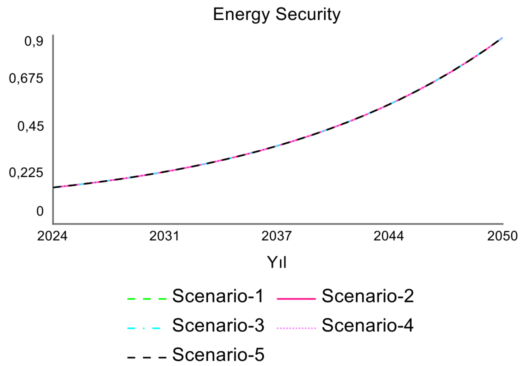

Figure 5. *Turkey's food security projection*

Currently, Turkey is self-sufficient in terms of food supply in quantity, even producing more than needed. However, this situation is changing towards 2050, and self-sufficiency in food is diminishing.

If even a small portion of agricultural production is used as a source for bioenergy supply, it is observed that food supply is significantly negatively affected. However, there is no significant positive impact on energy supply, energy import dependency, and thus energy security.

It is observed that achieving a certain annual increase in agricultural production positively affects food supply and consequently food security. Additionally, even at a very low rate, it is observed to have a positive effect on energy security.

Policies aimed at preserving agricultural areas have a positive effect on both food security and bioenergy potential.

Türkiye's reliance on imported fossil fuels is significantly high in meeting its energy demand. This situation has adverse effects in terms of environmental sustainability, import dependency, and energy security. Increasing renewable and environmentally friendly energy sources is essential to minimize these negative effects.

It is observed that there is an inverse relationship between bioenergy and food security depending on resource utilization. Globally, any increase in bioenergy use due to resource utilization has a suppressive effect on food security. Making agricultural energy production attractive could lead to competition between energy and food production, adversely affecting food supply. A contraction in food supply is predicted to have a negative impact on food inflation, availability, and accessibility.

Bioenergy serves as a renewable and domestic energy source, offering an alternative to fossil fuels. However, its potential alone is far from replacing fossil fuels in Turkey. Therefore, considering the current technological efficiency, converting only organic waste into bioenergy is observed as the most beneficial scenario for environmental sustainable.

Resource utilization is a critical issue in bioenergy production in Turkey. Redirecting a portion of agricultural production for this purpose not only has the potential to significantly affect food supply but also disrupts the balance in the food market. Disrupting the supply-demand balance would adversely affect Turkey's capacity for self-sufficiency. Therefore, to increase bioenergy supply, utilizing agricultural waste without causing competition between food and energy production and implementing policies that promote bioenergy investments are the most sustainable policies for Turkey.

Statements. This study is derived from the doctoral thesis titled "The effects of increases in bioenergy resource use on food safety, energy security and environment by system dynamics approach the example of Turkey" prepared by Dr. Muhammed Çelik.

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