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Air Pollution and Economic Sanctions in Iran

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Abstract

This study aims to simulate the future trends of carbon emissions under different international sanction scenarios in Iran. A System Dynamics (SD) model is developed and several variables that capture multiple levels of economic, social, and environmental concepts are taken into account. Our findings indicate that, despite Iran's sluggish economic growth, fossil fuel use and CO2 emissions will rise in the scenarios with international sanctions. Imposed sanctions on Iran exacerbate the environmental negative externalities through increasing energy intensity of economic sectors and consequently cause more CO2 emissions. Thus, based on our findings, prolonging international sanctions could be a major barrier to improving energy intensity and lowering CO2 emissions. Given the potential unintended environmental consequences of international sanctions, this study suggests that international communities, particularly sanctioning countries, should consider the environmental impacts of sanctions in their policy-making decisions in order to reduce emissions and related environmental damages.

Keywords: Sanctions; System Dynamics; Environmental Impacts; Simulation; CO2 Emissions; Iran; JCPOA.

JEL Codes: P18, F51, Q2.

1. Introduction

Economic sanctions may have consequences beyond the economic sector, including some unintended environmental impacts. The environmental effects of sanctions can be significant, including the limitation of imports of clean technologies that can lead to increased pollution and the breach of international environmental obligations to provide financial, technical, and scientific support to the sanctioned country (Madani, 2021; Saberpour et al, 2021; Fahimifard, 2020). While the economic consequences of sanctions have been well-documented, the environmental impacts on target countries, which may contribute to social conflict, have received less attention in the empirical literature. Assessing the environmental impact of sanctions is a complex task that involves numerous variables that operate within a dynamic framework with different causal loop diagrams and feedback structures (Yang et al, 2021; Wu et al, 2020). A majority of research on the environmental impacts of sanctions has used descriptive, statistical, and econometric models, but has not accounted for the causal loop diagrams and feedback structures

This study investigates the environmental impacts of international sanctions by focusing on energy-related CO_2 emissions using System Dynamics (SD). We analyze the driving factors and different policy scenarios related to energy-related carbon emissions in Iran under the imposed sanctions against Iran's economy, addressing the following questions:

1. What will be the future trends of carbon emissions in different economic sectors of Iran?
2. How will national-level energy consumption and CO_2 emissions be affected under different scenarios of Iran's sanctions and economic growth?

Our analysis makes several contributions to the existing literature. First, we add to the growing body of research on the economic effects of sanctions (e.g., Farzanegan, 2013; Khabbazan and Farzanegan, 2016; Gharehgozli, 2017; Esfahani and Rasoulinezhad, 2017; Haidar, 2017;

Dadpay and Tabrizy, 2021; Laudati and Pesaran, 2021; Zamani et al., 2021; Farzanegan and Fischer, 2021) by examining the environmental impacts of economic growth under sanctions.

In addition, we utilize a System Dynamics (SD) approach to examine the dynamic relationships and structure between the factors influencing economic growth, energy consumption, CO2 emissions, and sanctions. Many studies have been conducted on the connection between economic growth, energy consumption, and the environment, mostly using time series techniques and optimization models (Jayanthakumaran et al., 2012; Omri, 2013; Apergis and Payne, 2015; Wang et al., 2016; Chen and Lei, 2018; Wasti and Zaidi, 2020; Ahmad et al, 2016).

To the best of our knowledge, this is the first study to empirically simulate the interconnection between economic and environmental factors using System Dynamics to investigate the effects of sanctions. This method takes into account the feedback, delays, and nonlinearity inherent in modeling factors and is particularly well-suited for studying complex systems with interactions between various factors such as society, economy, environment, and technology (Ahmad et al, 2016; Yang et al, 2021). For a recent overview of the use of System Dynamics to inform policymaking with evidence, see Malbon and Parkhurst (2022). The design of the SD model in this study allows for simulation of the CO2 emitted by various economic sectors in Iran, including industry, agriculture, services, households, power plants, refinery plants, and transportation, and through various fossil fuels such as oil, gas, coal, and biomass.

This study identifies economic growth and energy intensity[1] as the main factors influencing energy consumption and CO2 emissions (Yang et al, 2021). We posit that international sanctions have a direct impact on the economic growth and energy intensity of the sanctioned country (Madani, 2021; Saberpour et al, 2021; Fahimifard, 2020; Proano et al, 2020; Madani,

[1] Energy intensity refers to the amount of energy required to produce a unit of output or activity. In this context, it is calculated as the ratio of energy consumption to gross domestic product (GDP).

2020; Mostafavi et al, 2014). Our findings indicate that international sanctions can exacerbate CO_2 emissions in Iran by causing a deterioration in energy intensity.

The remainder of the study is structured as follows: Section 2 provides a background on the case study of Iran and reviews the literature. Section 3 outlines the data and methodology. Section 4 presents the results of the model analysis. Finally, Section 5 concludes and offers policy recommendations.

2. Background and review of literature

Air pollution, including high levels of CO2, is a significant issue in Iran's major cities (Madani, 2021). Despite increasing concerns about the impact of rising CO2 concentrations on climate change, fossil fuels continue to be a major contributor to Iran's GDP growth and CO2 emissions (Hosseini, et al., 2019). Iran ranks eighth in the world in terms of total CO2 emissions, producing 0.7 billion tons in 2019, and twelfth in per capita CO2 emissions at 8.5 tons (Olivier and Peters, 2020). Figures 1 and 2 illustrate the trends in energy consumption and CO2 emissions in Iran.

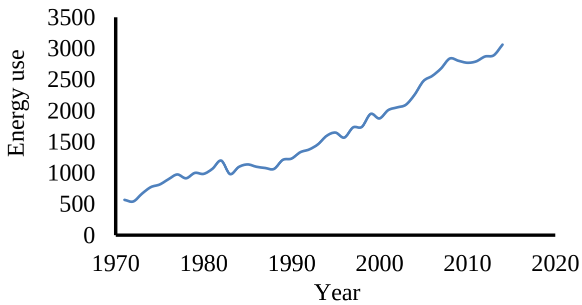

Fig. 1. Evolution of per capita energy use from 1970 to 2019 in Iran (kg of oil equivalent per capita)
Source: World Bank (2021)

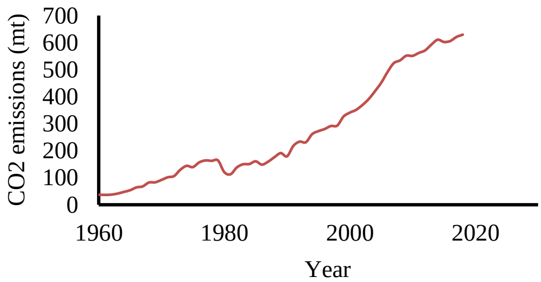

Fig. 2. Evolution of CO2 emission (mt) from 1970 to 2019 in Iran
Source: World Bank (2021)

Iran's high consumption of non-renewable energy sources is driven by several factors, including abundant fossil fuel reserves, population growth, reliance on fossil fuel power plants for electricity generation, and energy subsidies (Hosseini, et al., 2019). The abundance of cheap non-renewable energy makes it cost-effective to use these resources, and the majority of electricity for economic enterprises, such as industry, agriculture, and services, is generated by fossil fuel power plants (Pourkiaei et al., 2021). This close relationship between economic growth and fossil fuel consumption has been further exacerbated by international sanctions, which restrict the import of environmentally friendly technologies and block international aid for the environment (Madani, 2021; Saberpour et al, 2021; Fahimifard, 2020; Madani, 2020; Mostafavi et al, 2014). These sanctions have increased energy intensity and made economic production more expensive due to its environmental impact in Iran. To alleviate the negative effects of declining welfare caused by sanctions, the Iranian government continues to provide energy subsidies, which in turn leads to increased energy consumption over time.

Due to increasing concerns about global warming and climate change, countries have taken steps to control greenhouse gas emissions (Ye et al., 2021; Labzovskii et al., 2019). These efforts have been implemented internationally through the ratification of the Kyoto and Paris Climate Agreements, which aim to reduce greenhouse gas emissions (Radmehr et al., 2021), and domestically through measures such as sustainable economic growth planning, the promotion of renewable energy sources to reduce fossil fuel consumption, the implementation of pollution taxes, and the improvement of efficiency and standards in the transport sector (Lee, 2019). However, economic sanctions have led to a recession in Iran, hindering the country's ability to fulfill its obligations under the Paris Agreement to reduce CO2 emissions. This is because implementing these measures would exacerbate the economic recession and face opposition within the country (Hosseini et al., 2019). Data from the World Bank also shows a trend of deteriorating energy intensity in Iran from 2000 to 2020, likely influenced by the sanctions. (Figure 3).

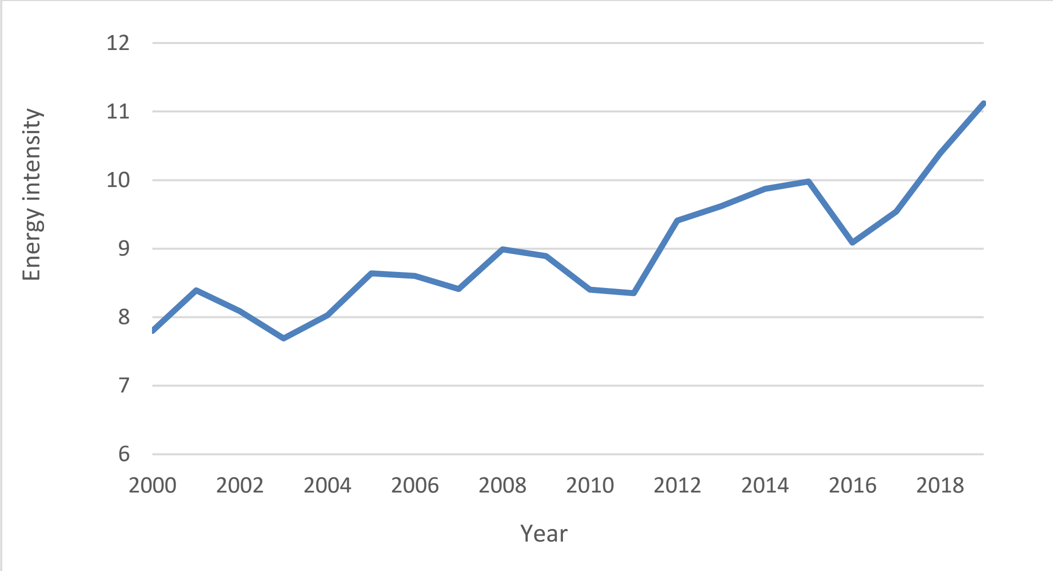

Fig. 3. Energy intensity level of primary energy (MJ/$2017 PPP GDP)
Source: World Bank (2021)

3. Data and methodology

3.1. Model Description

The research hypothesis is that sanctions, while disrupting and slowing economic growth, lead to an increase in energy-related CO2 emissions. To test this hypothesis, we use a System Dynamics (SD) model. The model is based on the Kaya identity[2] and considers the economic sectors based on whether energy is used as an input or final product, and whether it is deemed productive or non-productive (Lopez et al., 2014; Yang et al., 2020a). In order to align with the classification used in Iran's Energy Ministry energy balance sheet and for compatibility with the Central Bank of Iran (CBI) and the Statistical Center of Iran (SCI), the economic sectors in Iran that emit CO2 were categorized as industry, agriculture, services, household, power plants, refinery plants, and transportation.

In this model, the sectors of industry, agriculture, services, power plants, and refinery plants that contribute to economic value are considered productive. However, household energy

[2] The Kaya identity is a mathematical framework introduced in 1995 for analyzing the primary drivers of global CO2 emissions. It is a useful equation for quantifying total human-generated CO2 emissions, a greenhouse gas.

consumption, which largely goes towards meeting basic needs rather than generating economic value (Cui et al., 2019; Yang et al., 2021), has been considered a non-productive sector.

In the model, the portion of transportation activities that contribute to economic value is included in the services sector, while the portion related to household activities is treated as a non-productive sector in the form of a transportation variable. International sanctions are treated as an exogenous variable that directly affects the model's key variables. It is assumed that sanctions on Iran's economy, through limiting oil exports, reducing foreign investment, and restricting access to technology (Fahimifard, 2020; Saberpour et al, 2021; Madani, 2021), directly impact two key variables: economic growth (GR), defined as GDP changes, and the energy intensity (θ) of productive economic sectors, which in turn affects energy consumption and CO2 emissions (Figure 4). While the variables of GDP growth rate and energy intensity are the main factors directly affecting the energy consumption of productive economic sectors ($\mathrm{E_P}$), the non-productive sector's energy consumption (E_{NP}) additionally depends on population (POP), family size (FS), and the number of household vehicles (V).

As mentioned, energy-related CO2 emissions of each sector are directly affected by the energy consumption of that sector and its CO2 emissions coefficient (δ) (Table 1).

Various types of energy, including oil, gas, coal, electricity, biomass, nuclear power, and others, are used in the productive and non-productive sectors of Iran, but only those that emit CO2 are included in this model. The emission coefficients for each type of energy used in different sectors vary in this model and were based on data from Iran's Energy Balance Sheet. Table 1 describes all variables and parameters of the model.

Table 1. Variables Description in the Mode

Variable	Description
i	Productive economic sectors include agriculture, industry, service, power plants, and refinery plants.
J	Non-productive sectors including household and transportation
f	Types of energy source including oil, gas, coal, biomass, electricity
$\boldsymbol{\theta}$	Energy intensity
POP	Population
GDP	Real gross national production
GR	GDP growth rate
TE	Total energy consumption
E_P	Energy consumption in productive economic sectors
E_{NP}	Energy consumption in non-productive sectors
S	Energy mix structure: Share of each energy source type of energy consumption
FS	Family size
TCO2	Total CO2 emission
$\boldsymbol{\delta}$	CO2 emission intensity
$\boldsymbol{\gamma}$	Average energy consumption per vehicle
V	Number of household vehicles
$\boldsymbol{\rho}$	Energy consumption per household
$\boldsymbol{\beta}$	Vehicle per capita
t	Time
Sanction	International economic sanctions as an exogenous variable

3.2. Mathematical Model

This section outlines the main dynamic equations of the model. As shown in Equation (1), total energy consumption is calculated by summing the energy consumption of both the productive and non-productive sectors. The energy intensity of each sector is calculated by dividing the sector's final energy consumption by its GDP, and is defined as the energy consumption per unit of economic value added. In this model, the energy consumption of the transportation and household sectors is a function of population, but the former is also influenced by the number of vehicles per capita and the average energy consumption per vehicle (Equation 5), while the latter is defined as a function of population net growth, family size, and energy consumption per household (Equation 6).

Total CO2 emissions from productive and non-productive activities (TCO2) are calculated using Equation (7). The CO2 emissions intensity for each fuel type in each sector is calculated by dividing the emissions produced by each fuel type in each sector ($Co2_{jf}$) by the energy consumption of that fuel in that sector ($E_{if}\ and\ E_{jf}$).

$$TE_t = E_{P_t} + E_{NP_t} \tag{1}$$

$$E_{P_t} = \sum_{i=1}^{n} GR_{it} \,.\, GDP_{it-1} . \frac{E_{P_{it}}}{GDP_{it}} = \sum_{i=1}^{n} GR_{it} \,.\, GDP_{it-1} . \theta_{it} \tag{2}$$

$$n = 5\,, \qquad i = agr, ind, ser, power, refinery$$

$$\theta_{it} = \frac{E_{P_{it}}}{GDP_{it}} \tag{3}$$

$$E_{NP_t} = \sum_{j=1}^{m} E_{NP_{jt}} \;, \qquad m = 2\,, \quad j = Trans, House \tag{4}$$

$$E_{NP_{Trans\,t}} = POP_t \,.\, \frac{V_{t-1}}{POP_{t-1}} \,.\, \frac{E_{NP_{Trans\,t-1}}}{V_{t-1}} = POP_t \,.\, \beta_{t-1} \,.\, \gamma_{t-1} \tag{5}$$

$$E_{House_t} = PGR_t . POP_{t-1} . \frac{1}{FS_{t-1}} . \left(\frac{E_{House_{t-1}}}{POP_{t-1}/FS_{t-1}} \right) = PGR_t . POP_{t-1} . \frac{1}{FS_{t-1}} \rho_{t-1} \tag{6}$$

$$TC02_t = \sum_{i=1}^{n} \sum_{f=1}^{l} E_{P_{it}} \,.\, S_{ift-1} \,.\, \frac{Co2_{ift-1}}{E_{ift-1}} + \sum_{j=1}^{m} \sum_{f=1}^{l} E_{NP_{jt}} \,.\, S_{jft-1} \,.\, \frac{Co2_{jft-1}}{E_{jft} - 1} \tag{7}$$

$$= \sum_{i=1}^{n} \sum_{f=1}^{l} E_{P_{it}} \,.\, S_{ift-1} \,.\, \delta_{ift-1} + \sum_{j=1}^{m} \sum_{f=1}^{l} E_{NP_{jt}} \,.\, S_{jft-1} \,.\, \delta_{jft-1}$$

3.3. SD Model

System Dynamics (SD) is a simulation technique that is widely used in decision making, policy planning, and evaluation (Kunche and Mielczarek, 2021; Dong et al., 2012). It allows for the examination of causal relationships and dynamic changes between various elements in a complex system (Dong et al., 2018; Yang et al., 2021).

SD extensively employs cause-and-effect relationships and feedback systems, which help identify complex behavioral patterns over time and allow for the study of long-term unanticipated consequences and policy resistance (Kunche and Mielczarek, 2021). The modeling process for SD begins with defining the object, specifying the system boundary, and constructing the causal chains of factors in the system (Ahmad et al., 2016; Yang et al., 2020b). The purpose of this study is to model and simulate the potential national-level impacts of Iran's sanctions and economic growth on energy consumption and CO_2 emissions, and to forecast future carbon emission trends in various economic sectors of Iran.

In order to achieve this goal, we employed a system dynamics model that took into account various economic, social, and environmental factors and their interrelationships. This model consisted of three subsystems: the Productive Economic-Energy Subsystem (PEES), the Social-Non-Productive Economic-Energy Subsystem (SNEES), and the Energy-Emission Subsystem (EES). We used the variables listed in Table 1 to create stock-flow diagrams and mathematical equations that described the interactions between these subsystems.

3.3.1. Productive Economic-Energy Subsystem (PEES)

GDP has been identified as a significant factor in the relationship between energy consumption and CO_2 emissions in various studies (Proano et al., 2020; Ye et al., 2021; Yang et al., 2021; Kunche and Mielczarek, 2021; Ahmad et al., 2016; Liu et al., 2015). It is well established that energy consumption and economic growth are closely linked, with a strong positive correlation between total economic output and energy consumption (Wu et al., 2020; Li et al., 2020).

The Productive Economic-Energy Subsystem (PEES) in our model illustrates the relationship between the economic growth of productive sectors and their energy consumption. This subsystem includes the GDP of Iran's productive economic sectors, including agricultural domestic production (AGR-GDP), industry domestic production (IND-GDP), service domestic production (SER-GDP), power plants GDP (POW-GDP), and the refinery sector GDP (REF-GDP). CO_2 emissions in this subsystem are generated by economic activities that create added value.

Energy intensity is an indicator used to measure energy efficiency at the national level, and is calculated by dividing energy consumption (either final or primary) by GDP. It is often referred to as "energy consumption per added value" (Rahmani et al., 2020; Wu et al., 2020; Yang et al., 2021; Iran Energy Balance, 2017; Ebrahimi and Pilevari, 2021). In our model, the energy intensity of each economic sector is represented by the following indexes: AGR-E-Intensity (agriculture), IND-E-Intensity (industry), SER-E-Intensity (services), POW-E-Intensity (power plants), and REF-E-Intensity (refinery). Sanctions, which are external factors that influence the economic growth rate and energy intensity of productive sectors, will also affect energy consumption and CO2 emissions (Fig. 4).

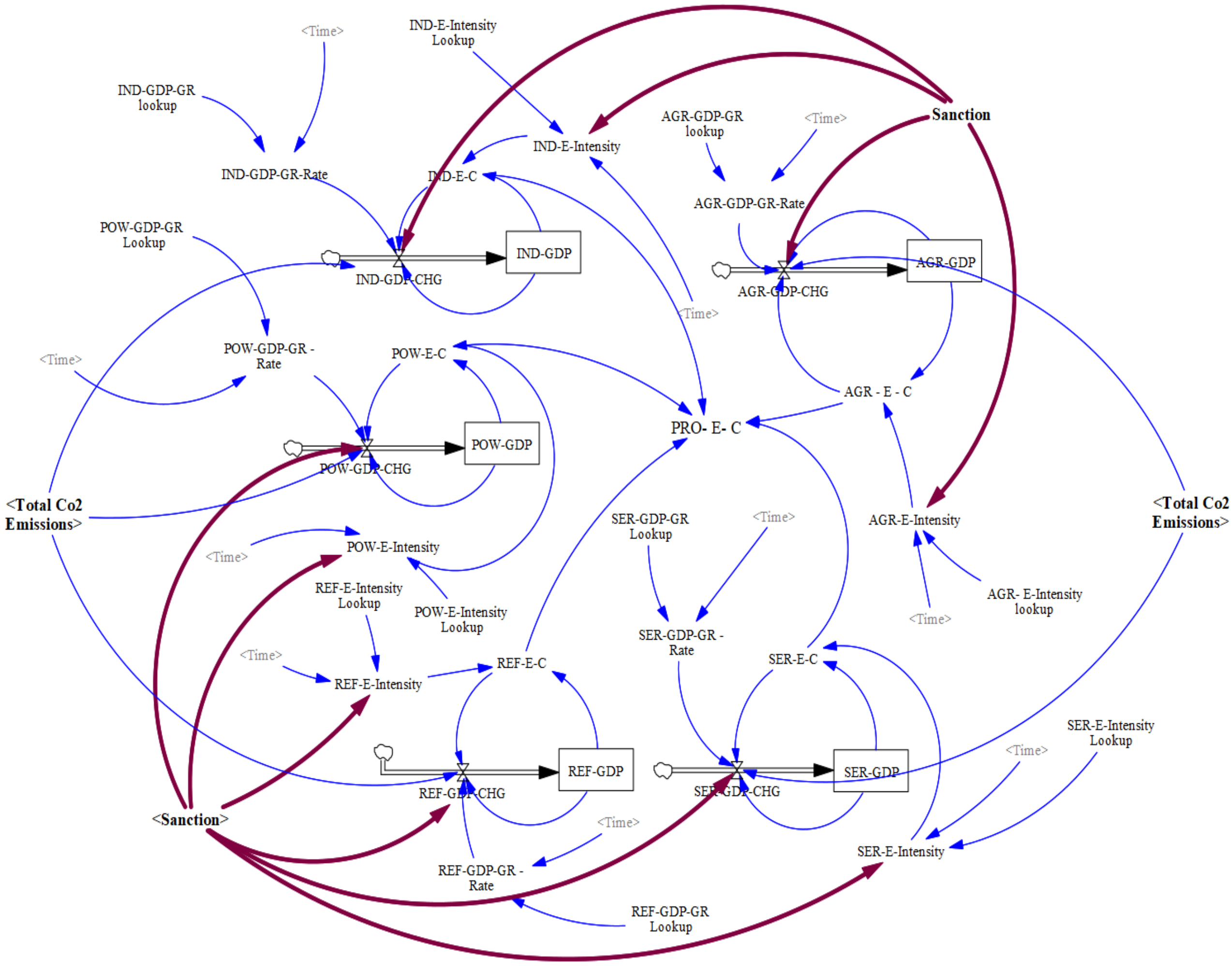

Fig. 4. Stock-flow diagram of the Productive Economic-Energy Subsystem

3.3.2. Social-Non-Productive Economic-Energy Subsystem (SNEES)

Non-productive economic emissions are largely due to providing basic guarantees for livelihoods that do not create economic value (Yang et al., 2021; Cui et al., 2019). In this sector, increasing energy consumption is related to the growing population, per capita consumption, and changing consumer needs, behavior, and lifestyles (Rahmani et al., 2020; Satterthwaite, 2009). The CO_2 emissions of this sector, which includes household and transportation, are influenced by factors such as population size, family size, number of vehicles, and energy consumption patterns (Cui et al., 2019). Within this sector, household energy consumption (House-E-C) is determined by variables such as population (POP), average household size (POP-per-household), and energy consumption per household (E-C-per-household). Meanwhile, the energy consumption of the transportation sector is largely influenced by the number of vehicles and energy usage per vehicle. As shown in Fig. 5, population size and number of vehicles are considered stock variables, while birth rate (BR), death rate (DR), and vehicle net change (Vehicle – Net – CHG) are considered flow variables.

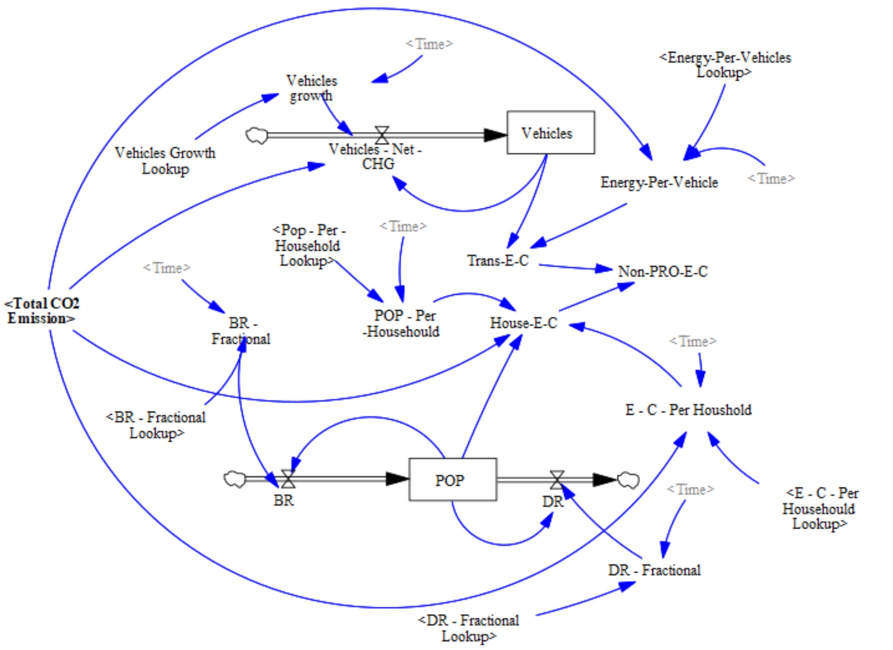

Fig. 5. Stock-flow diagram of Social-Non-Productive Economic-Energy Subsystem

3.3.3. Energy –Emission Subsystem (EES)

Energy availability has long been a major focus of political discussions worldwide due to its role as a driving force behind economic growth. However, it is also a significant contributor to global climate change and CO_2 emissions (Rahmani et al., 2020).

According to a report from Iran's energy ministry in 2017, there are six main sources of CO2 emissions in the country: industry, agriculture, service & household, oil, gas refinery, transportation, and power plants (Iran Energy Balance, 2017). These sectors and the factors that influence their emissions are depicted in EES (Fig. 6 to Fig. 11). Essentially, this subsystem represents the connection between the economic and social components and the environment in the overall system, with factors such as GDP growth in economic sectors, population growth, and vehicle growth linked to carbon emissions.

In the model, energy consumption in the service and household sectors is combined and represented as SEHO-E-C (Fig. 6)[3]. The variables for cumulative CO2 emissions in these sectors are considered stock variables, including AGR-CO2-E, IND-CO2-E, SEHO-CO2-E, Power-CO2-E, TRANS-CO2-E, and Refinery-CO2-E, while their annual changes in CO2 emissions are considered flow variables. In this study, the total annual and cumulative carbon emissions from energy consumption are calculated by summing the CO2 emissions from these sectors and are represented as the flow and stock variables Total-CO2-E-CHG and Total-CO2-E, respectively. The energy-CO2 emission subsystem in Iran's carbon emission system includes driving factors such as energy type (Oil, Gas, Electricity, Coal, Biomass), CO2 emission coefficients for all types of energy, and the combination of energy consumption.

[3] At the international level, statistics on the energy sector and GDP are provided based on the International Standard Industrial Classification of all economic activities (ISIC), but in Iran, energy sector statistics are not recorded by any of the energy authorities. Therefore, due to differences in definitions, it is not possible to calculate some indicators (at least separately for consumer sectors), such as energy intensity or CO2 emission coefficient, etc., which is based on two categories of energy sector information and the value-add of each sector (Iran Energy Balance, 2017).

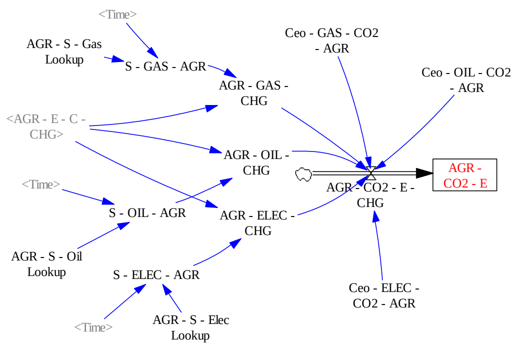

Fig. 6. Agriculture CO2 Emissions flow diagram

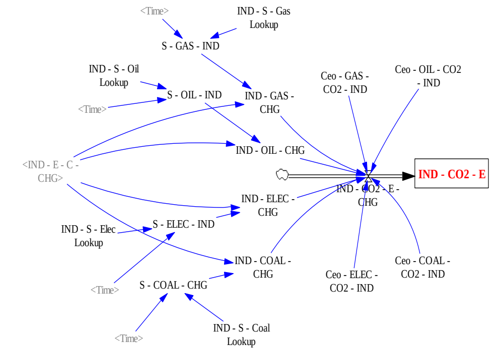

Fig. 7. Industry CO2 Emissions flow diagram

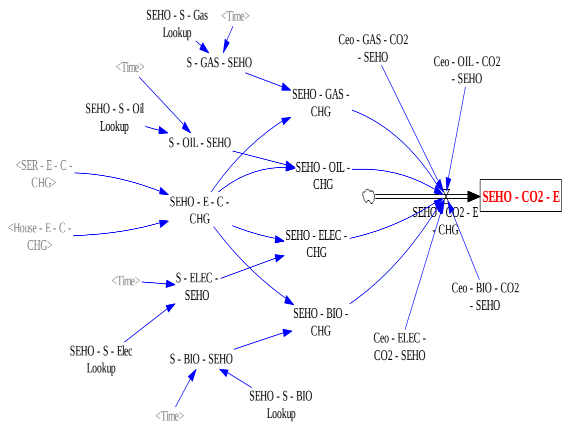

Fig. 8. Service and Household Sectors CO2 Emissions flow diagram

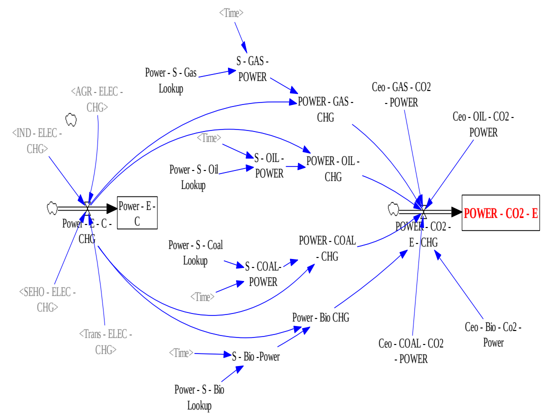

Fig. 9. Power sectors CO2 emissions flow diagram

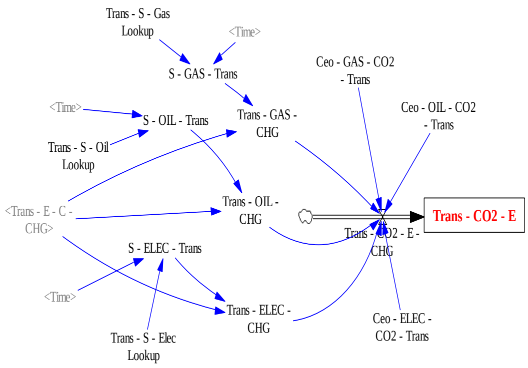

Fig. 10. Transportation sector CO2 emissions flow Diagram

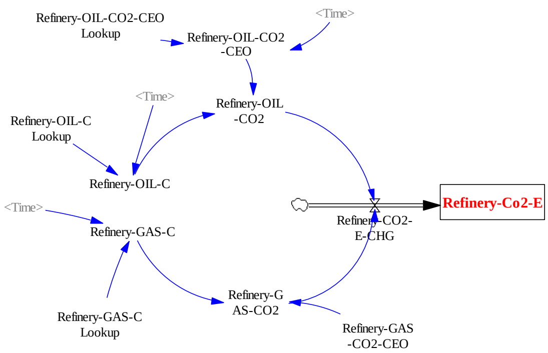

Fig. 11. Oil and Gas refinery sector CO2 emissions flow diagram

3.4. Data Collection

To examine the impact of various international sanction scenarios on energy consumption and CO2 emissions in Iran, we used a SD model and industrial strength simulation software

(Vensim) to analyze driving factors such as energy intensity, fuel combination, and fuel-specific emission coefficients from 2008 to 2028. The data for this study were primarily obtained from the Statistical Center of Iran (SCI), Iran's annual energy balance sheet published by the Ministry of Energy (Iran Energy Balance, 2017), the Central Bank of Iran's (CBI) statistical yearbooks, and the Statistical Center of Iran, with 2008 serving as the base year.

3.5. Model Validation

Model validation is a crucial aspect of system dynamics modeling that ensures the validity of the model's results (Barlas, 1996) and establishes trust in the model's usefulness for its intended purposes (Barlas, 1996; Atamer Balkan et al., 2021). Model validation is an ongoing process that occurs throughout the model conceptualization, construction, and communication stages (Forrester and Senge, 1979). Structural assessment and boundary adequacy tests were used in this study to assess the endogeneity and homogeneity of each variable and the compatibility of the model's relationships with existing knowledge about economic growth, energy consumption, and CO2 emissions. The SD model's ability to reproduce historical data was also evaluated. The mean absolute percentage error between actual data and simulated values from 2008 to 2017 was used to measure the validity of the SD model. The model's effectiveness was then assessed by comparing simulation values to actual values during this period in two ways: the accuracy of historical simulation (selected years 2010, 2015, and 2017) and the credibility of prediction (2018-2020). The results showed a high degree of similarity between the simulated values and the actual values, with relative errors no more than 5% (in most cases, no more than 1%, with a maximum deviation of 4.42%). These results demonstrate that the model performs well in both simulation and prediction (see Table 2).

Table 2
Validity of the SD Model

Variable		2010	2015	2017	2008-2020
GDP of Agriculture Sector (Milliard Rials)	Actual Value	335920	424173	456018	MAPE= 3.2
	Simulation Value	321811.4	408478.8	444617.3	
	Error (%)	-3.3	-3.7	-2.5	
GDP of Industry Sector (Milliard Rials)	Actual Value	1591269	1545843	1659600	MAPE=1.6
	Simulation Value	1567399.8	1586035.2	1681174.7	
	Error (%)	-1.5	2.6	1.3	
GDP of Service Sector (Milliard Rials)	Actual Value	2417018.506	2599259.46	2773914.872	MAPE= 4.42
	Simulation Value	2291333.544	2487491.303	2882097.552	
	Error (%)	-5.2	-4.3	3.9	
Total Population (Person)	Actual Value	74129655	79586795	81037505	MAPE= 0.28
	Simulation Value	74161088	79328136	81686376	
	Error (%)	0.04	-0.3	0.8	
Number of Vehicles	Actual Value	19889981	27836600	31771110	MAPE=3.71
	Simulation Value	20586130.34	28977900.6	29674216.74	
	Error (%)	3.5	4.1	-6.6	
Annual Energy Consumption (Barrel)	Actual Value	1134700000	1276500000	1343300000	MAPE= 0.083
	Simulation Value	1134790000	1275190000	1346310000	
	Error (%)	0.007	-0.102	0.22	
Annual CO2 Emission (Ton)	Actual Value	530409734	567295275	598502388	MAPE=2.65
	Simulation Value	543139790.8	558218550.6	583539828.3	
	Error (%)	2.4	-1.6	-2.5	

3.6. Scenarios Design and Setting

Iran's economy is characterized by its hydrocarbon, agriculture, and service sectors, as well as a significant state presence in manufacturing and financial services. The country is the second-largest holder of natural gas reserves and the fourth-largest holder of proven crude oil reserves. While Iran's economy is relatively diversified compared to other oil-exporting countries, economic activity and government revenues are still heavily dependent on oil revenues, leading to volatility (World Bank, 2021).

Research has shown that international sanctions have had varying but significant impacts on Iran's economic growth, and should be taken into consideration as key drivers that affect various economic and environmental indicators in Iran. Sanctions have placed restrictions on Iran's access to foreign investment, new technologies, and services, and have also blocked international aid and frozen Iranian foreign assets, thereby impacting various sectors of Iran's economy over the past few decades. The Joint Comprehensive Plan of Action (JCPOA) between Iran and the P5+1 and EU was announced on July 14, 2015 in Vienna, under the framework of the April 2015 Iran nuclear deal, leading to the termination and suspension of some sanctions from 2015 to 2017. However, after the failure of the JCPOA, sanctions against Iran were reimposed in 2018. As a result, international economic sanctions are one of the main factors influencing Iran's economic growth, along with changes in energy intensity in different economic sectors, and serve as the foundation for the various scenarios examined in this study. This study considers three periods of Iran's economic growth: before the JCPOA (2008-2015), during the implementation of the agreement (2016-2017), and after the return and intensification of sanctions (2018-2020), in combination with three modes of energy intensity change: improvement, deterioration, and unchanged. Based on the results of sensitivity analysis, model validation, and the current classification of economic growth, seven policy scenarios were established, as shown in Table 3.

Table 3
Definitions of different scenarios.

Scenario	Definition
Baseline	Current Status
Scenario 1	Sanctions before JCPOA: Annual growth rate: average of 2008-2015, Annual energy Intensity change: No Changing
Scenario 2	Sanctions before JCPOA: Annual growth rate: average of 2008-2015, Annual energy Intensity change: 2.3 % in all sectors
Scenario 3	Lifting of sanctions (JCPOA): Annual growth rate: average of 2016-2017, Annual energy Intensity change: No Changing
Scenario 4	Lifting of sanctions (JCPOA)- Annual growth rate: average of 2016-2017 - Annual energy Intensity change: -1.96 % in all sectors
Scenario 5	Re-establishment of sanctions after JCPOA: Annual growth rate: average of 2018-2020, Annual energy Intensity change: No Changing
Scenario 6	Re-establishment of sanctions after JCPOA -Annual growth rate: average of 2018-2020, Annual energy Intensity change: 7.96 % in all sectors

4. Results and Discussion

4.1 Analysis of baseline scenario and CO_2 emissions in the current status

After validating the model, historical data for the variables of interest were entered into the model for the period 2008-2020, and the current status of economic growth, energy consumption, and CO_2 emissions was estimated. The baseline scenario was then created based on this historical data (without any limitations on the model) to simulate and predict the trend of energy consumption and CO_2 emissions by the end of 2028. The baseline scenario represents the scenario in which no socio-technical constraints are implemented to reduce CO_2 emissions. The results of the baseline scenario (Fig. 12 (a,b) and Fig. 13) show that, under the current conditions of economic growth and energy intensity in economic sectors, energy consumption and CO_2 emissions will continue to grow at an increasing rate. Energy intensity, which is used to evaluate the energy consumption of each economic activity or sector, has fluctuated over the past two decades in Iran and has generally been trending upwards (World Bank, 2022). According to some researchers, sanctions have contributed to this trend (Madani, 2021). The baseline scenario predicts that CO_2 emissions will increase in all economic sectors by 2028, with no decreasing trend in emissions in any sector. While the cumulative amount of CO_2 emissions in the power plant sector over time is higher than in other sectors, transportation will have a higher annual emission rate. In the baseline scenario, economic growth (based on the historical trend) will continue without any policy restrictions on CO_2 emissions, although the continuation or improvement of economic growth and changes in energy consumption over time will depend on the presence or absence of economic sanctions. Based on Iran's oil resources and reliance on fossil fuels, annual CO_2 emissions in the baseline scenario will maintain their upward trend and will reach over 872 million tons per year in 2028, indicating that CO_2 emissions will continue to rise significantly if emission limits policies are not implemented.

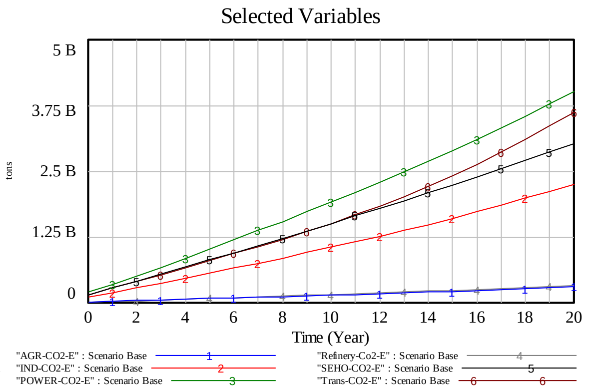

Fig. 12(a). Cumulative CO2 Emission of different sectors in Base scenario

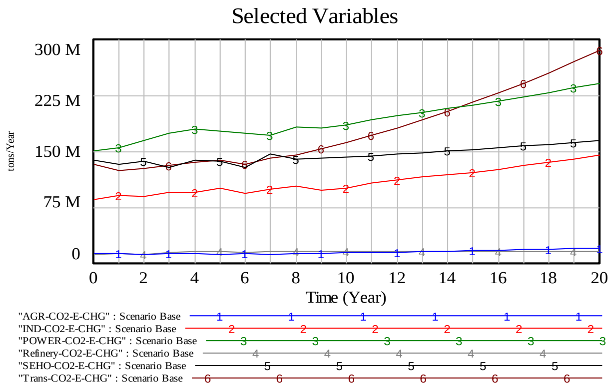

Fig. 12(b). Annual CO2 emission of different sectors in Base scenario

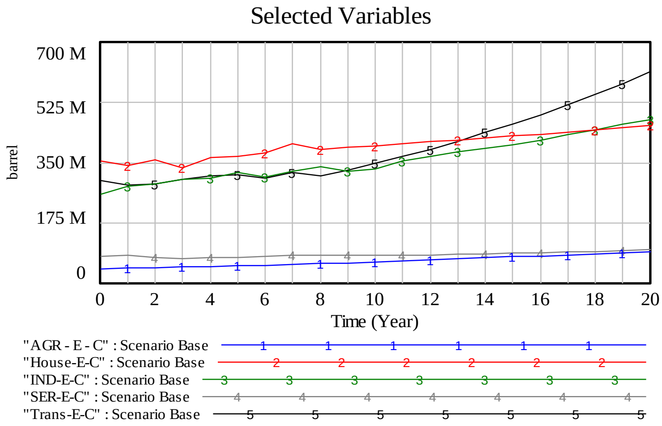

Fig. 13. Energy consumption of different sectors in the Base scenario

Fig. 13 illustrates the trend of energy consumption in different economic sectors over time. According to the baseline scenario, continued economic growth will be accompanied by an increase in energy consumption in all sectors studied. The model forecasts also indicate that energy consumption in both the industry and transportation subsectors will increase at an increasing rate in the coming years and will surpass that of the household sector. Energy consumption in the services, agriculture, and household sectors is increasing at a modest rate over time. Therefore, to devise policies for more efficient energy consumption, the industry and transportation sectors should be the main focus of environmental and energy policies. The findings also show that, under this scenario, total annual energy consumption in various economic sectors in 2028 will reach 1905 Million Barrel of Oil Equivalent (MMBOE). This represents an upward trend in energy consumption, while Yang et al (2021) used a SD model to simulate that annual energy consumption in some developed countries, including the United States, Germany, and Japan, will decline after reaching its peak. While it is expected that the share of fossil energy will gradually decrease as fossil energy reserves dwindle and extraction costs increase over time, through the replacement of non-renewable resources, if careful energy policies and emission limits are not implemented, by 2028, consumption of fossil energy resources and CO2 emissions in Iran will continue to rise incrementally. Given Iran's energy resource extraction capacity (an average annual energy supply equivalent to 1666.8 million barrels of crude oil over a 10-year period, an average growth rate of 6.2% due to technology improvement and the discovery of new oil fields, and an average 50-year energy consumption growth rate of about 7% (calculated based on Iran's energy balance sheet, 2017)), the available fossil resources will not be able to meet national needs for more than 40 years or more.

4.2. Policy scenario analysis and the impacts of sanctions on CO2 emissions

To properly compare the national level impacts of energy consumption and CO2 emissions under different sanctions scenarios, Iran's economy and its indicators were divided into three periods: before the nuclear agreement with mild economic sanctions (before JCPOA), the nuclear agreement-suspension period (JCPOA), and the period of intensification of economic sanctions (after JCPOA) (Table 3). Using sensitivity analysis based on the SD method and the factors affecting energy consumption and CO2 emissions, these two variables were estimated by designing six possible scenarios for the coming years. The results of the sensitivity analysis for Iran's entire economy are shown in Fig. 14 (a,b).

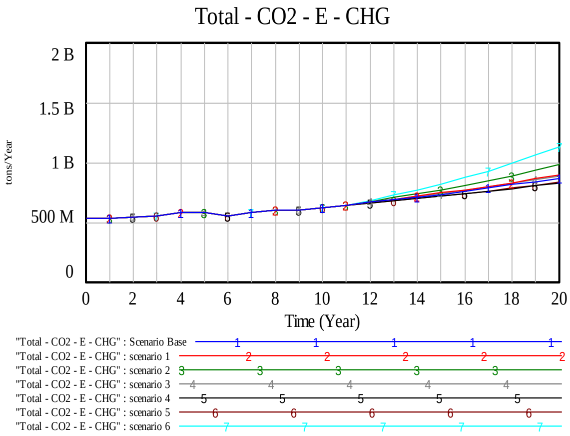

Fig. 14(a). Fig. Total annual CO2 emission of Iran under different scenarios

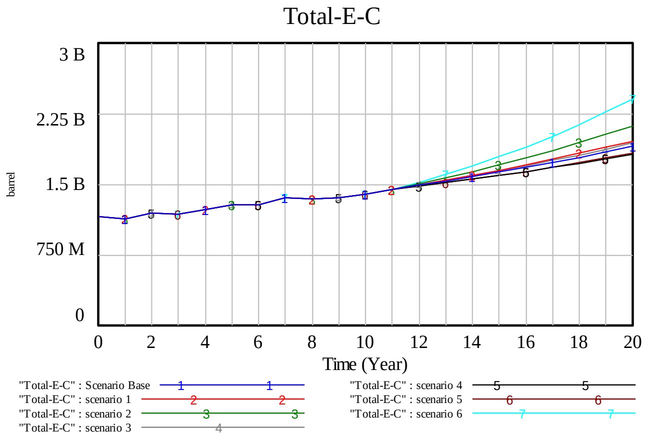

Fig. 14(b). Total annual Energy consumption of Iran under different scenarios

The results demonstrate that under scenario 2 with economic sanctions before the JCPOA, in which energy intensity increases by 2.3% annually, annual CO_2 emissions will reach 981 million tons in 2028, 12.5% more than the base scenario. With the JCPOA agreement and a smooth increase in the economic growth of some sectors, energy intensity in economic activities improved by about 1.96% annually. In scenario 4, where the economic situation after lifting sanctions due to the JCPOA has been simulated, annual fossil fuel energy consumption and CO_2 emissions will decrease by more than 4.5% and 5%, respectively, compared to the baseline scenario. It is clear that by lifting and suspending some sanctions after the JCPOA, due to easier access to new technologies and an increase in GDP, energy intensity in economic activities improved and mitigated CO_2 emissions. The findings reveal that under scenario 6, where international economic sanctions against Iran have been reinstated and intensified, total annual CO_2 emissions will increase significantly. The simulated model predicts that if the imposed sanctions after the destruction of the JCPOA continue, carbon dioxide emissions will increase significantly compared to the other scenarios. Given the conditions of the sanctions, the government will try to maintain energy subsidies to reduce household living and firm production costs, which sharply increase consumption of fossil fuels and energy-related emissions.

As the sensitivity analysis of the SD model shows, scenario 6 (conditions for the continuation of economic sanctions) shows the highest annual CO_2 emissions of 1135 million tons in 2028, due to the deterioration of energy intensity. Furthermore, scenario 4, which corresponds to the period of the nuclear agreement with the highest economic growth rate, shows a better situation in CO_2 emissions. This result demonstrates that, despite the positive relationship between economic growth and CO_2 emissions, the increase in economic growth after the nuclear deal, due to the renovation of firms' equipment and the resulting improvement in energy intensity, has caused a reduction in CO_2 emissions. Emissions and energy consumption by economic sectors under different scenarios are shown in Fig. 15 to 18.

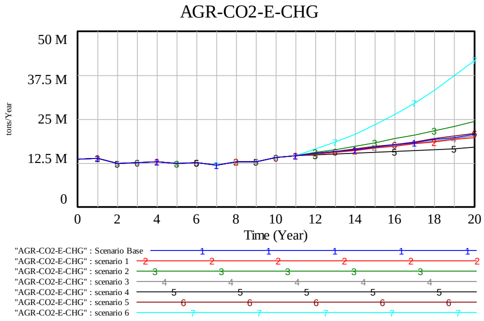

Fig. 15(a). Annual CO2 emission of agriculture sector under different scenarios

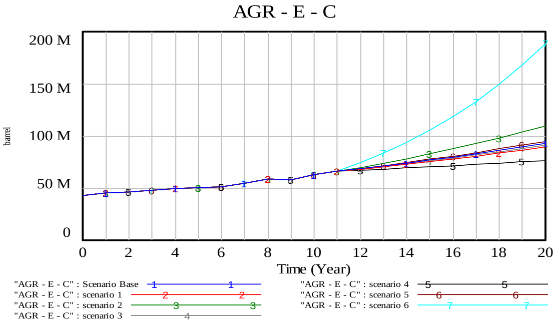

Fig. 15(b). Annual Energy consumption of the agriculture sector under different scenarios

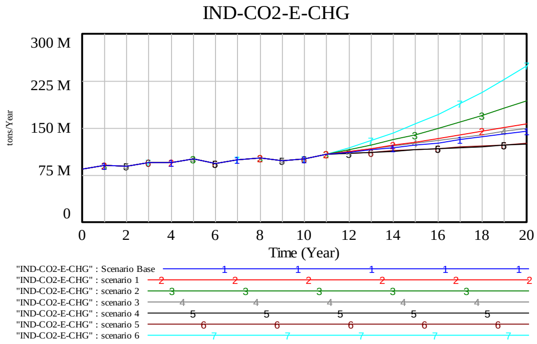

Fig. 16(a). Annual CO2 emission of industry sector under different scenarios

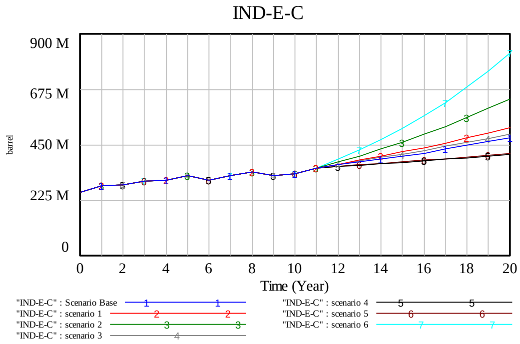

Fig. 16(b). Annual Energy consumption of industry sector under different scenarios

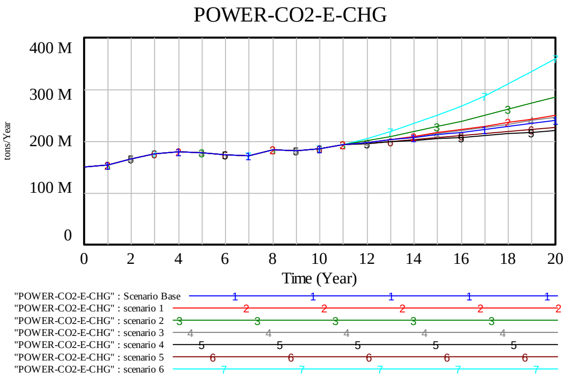

Fig. 17(a). Annual CO2 emission of power plants under different scenarios

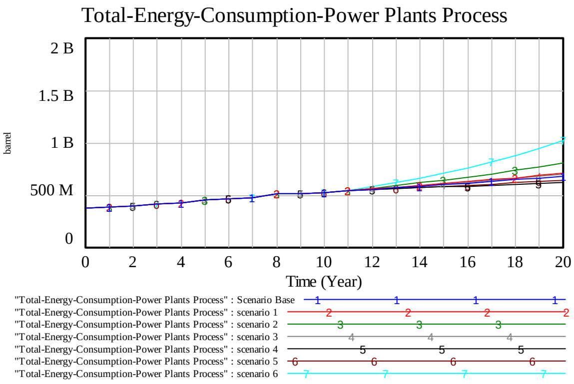

Fig. 17(b). Annual Energy consumption of power plants under different scenarios

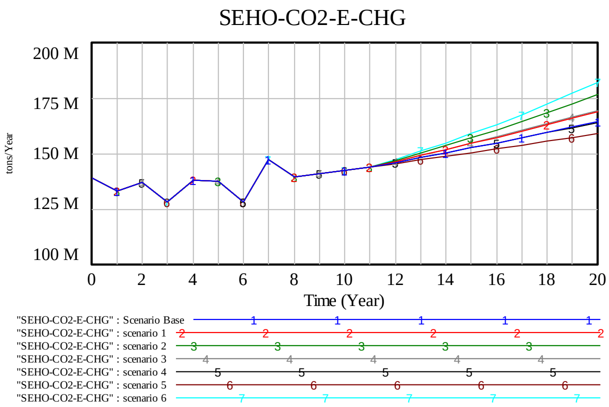

Fig. 18. Annual CO2 emission of Service and Household under different scenarios

Simulation results showed that the agriculture sector is expected to have the lowest CO2 emissions in 2028 among all economic sectors. However, the effects of sanctions on CO2 emissions varied among the different scenarios. In scenario 2, where sanctions were in place before the JCPOA, annual CO2 emissions in the agriculture sector were projected to be 24.2 million tons in 2028. Lifting the sanctions in scenario 4 reduced these emissions to 16.9 million tons. On the other hand, scenario 6, with the most severe sanctions, resulted in a 147% increase in CO2 emissions to 41.8 million tons in the agriculture sector. The industry sector showed a similar trend in CO2 emissions under the different scenarios. (Fig. 16(a)). In scenario 1 and 2, emissions in this sector were estimated to be 157 and 193 million tons at the end of the simulation period, respectively. These emissions decreased to 149 and 124 million tons in scenarios 3 and 4, respectively, where the sanctions were lifted. However, the re-establishment and intensification of sanctions in scenario 6 resulted in more than 249 million tons of carbon dioxide emissions in the industry sector, a 100% increase. Scenario 4 had the lowest CO2 emissions among all scenarios. In the power sector, scenario 6 had the highest CO2 emissions, with an annual average of 360 million tons All scenarios showed energy consumption in the power sector at the end of 2028 ranging from 620 to 1020 MMBOE, while the industrial sector, a highly energy-intensive sector, had energy consumption of less than 600 MMBOE in all scenarios except scenario 6. Since much of the country's electricity comes from fossil fuel power plants, this result is expected. C Transitioning to renewable energy sources in the electricity industry could significantly reduce these emissions. Among the various scenarios analyzed, scenario 4 - which involves decreasing energy intensity and lifting economic sanctions - has the lowest projected CO2 emissions in the power sector. Carbon emissions in the service and household (SEHO) sectors are also illustrated in Fig. 18. In the service and household sector, scenario 6 has the highest projected CO2 emissions in 2028 at 182 million tons. The findings indicate that reducing energy intensity in economic activities will be key to reducing CO2 emissions in the future.

5. Conclusion and Policy Implications

This study aimed to understand the factors that drive, and the future trends and policy options for energy-related carbon emissions in Iran, with a focus on the impact of economic sanctions. To do this, we developed a system dynamics model and tested its reliability using structural assessment, boundary adequacy, and the ability to reproduce historical data. Our initial hypothesis was that the implementation of sanctions, while disrupting and slowing economic growth, would lead to an increase in energy-related CO2 emissions.

To investigate the influence of various factors on energy-related carbon emissions in Iran, we developed several scenarios that considered changes in international economic sanctions, economic growth, and energy intensity in different economic sectors. The results showed that in the baseline scenario, fossil fuel energy consumption and CO2 emissions are expected to continue increasing until 2028. The implementation of the Joint Comprehensive Plan of Action (JCPOA) agreement, which temporarily lifted some economic sanctions, led to a decrease in carbon emissions due to an improvement in energy intensity. However, after the failure of the JCPOA in 2018, the re-imposition of previous sanctions, and the establishment of new sanctions slowed economic growth and increased energy intensity in all sectors. This led to a significant increase in energy consumption and carbon emissions, particularly in scenario 6, which saw a 147% increase in carbon emissions compared to scenario 4, demonstrating the significant impact of sanctions on CO_2 emissions in Iran.

Our findings suggest that continuing economic sanctions hinder the improvement of energy intensity and the reduction of CO_2 emissions in Iran. As previously noted, sanctions have not directly caused environmental problems in Iran, but they have had indirect environmental impacts by restricting access to technology, services, and expertise; blocking international aid for the environment; and increasing the natural resource intensity of Iran's economy (Madani, 2021). While previous research has generally found a positive relationship between economic growth and CO_2 emissions, our results show that during the period of the JCPOA, increased economic growth was accompanied by a decrease in energy-related CO_2 emissions due to an improvement in energy intensity. However, the re-imposition of sanctions has made economic activities more costly to the environment and will likely have unintended negative environmental consequences, including increased CO_2 emissions. Therefore, if the international community aims to reduce CO_2 emissions, simply setting emission quotas based on the Paris Agreement may not be effective in the case of Iran. Policymakers, particularly in the countries imposing sanctions, should consider the environmental consequences of sanctions in their decision-making processes.

Disclosure statement

No potential conflict of interest was reported by the author(s).

References

Ahmad, S., Tahar, R. M., Muhammad-Sukki, F., Munir, A. B., & Rahim, R. A. (2016). Application of system dynamics approach in electricity sector modelling: a review. *Renewable and Sustainable Energy Reviews*, 56, 29–37. https://doi.org/10.1016/j.rser.2015.11.034

Apergis, N., & Payne, J. E. (2015). Renewable energy, output, carbon dioxide emissions and oil prices: Evidence from South America. *Energy Sources, Part B: Economics, Planning, and Policy,* 10(3), 281-287. https://doi.org/10.1080/15567249.2013.853713

Atamer Balkan, B., Lindqvist, A. N., Odoemena, K., Lamb, R., Tiongco, M. A., Gupta, S., Peteru, A., & Menendez, H. M. (2021). Understanding the impact of COVID-19 on agriculture and food supply chains: system dynamics modeling for the resilience of smallholder farmers. *Journal of Food System Dynamics*, 12(3), 255-270. https://doi.org/10.18461/ijfsd.v12i3.89

Barlas, Y. (1996). Formal aspects of model validity and validation in system dynamics. *System Dynamics Review*, 12(3), 183-210. https://doi.org/10.1002/(SICI)1099-1727(199623)12:3%3C183::AID-SDR103%3E3.0.CO;2-4

Central Bank of Iran (CBI). (2021). *Selected findings of the 2021 national accounts of Iran*. Available online: https://www.cbi.ir/page/2072.aspx.

Chen, W., & Lei, Y. (2018). The impacts of renewable energy and technological innovation on environment-energy-growth nexus: New evidence from a panel quantile regression. *Renewable Energy*, 123, 1-14. https://doi.org/10.1016/j.renene.2018.02.026

Cui, P., Xia, S., & Hao, L. (2019). Do different sizes of urban population matter differently to CO2 emission in different regions? Evidence from electricity consumption behavior of urban residents in China. *Journal of Cleaner Production*, 240, 118207. https://doi.org/10.1016/j.jclepro.2019.118207

Dadpay, A., & Tabrizy, S. (2021). Political agreements and exporting activities: an empirical assessment of the effects of the JCPOA agreement on Iran's exports. *Comparative Economic Studies*, 63(1), 147-180. https://doi.org/10.1057/s41294-020-00136-x

Dong, K., Hochman, G., Zhang, Y., Sun, R., Li, H., & Liao, H. J. E. E. (2018). CO2 emissions, economic and population growth, and renewable energy: empirical evidence across regions. *Energy Economics*, 75, 180-192. https://doi.org/10.1016/j.eneco.2018.08.017

Dong, X., Li, C., Li, J., Huang, W., Wang, J., & Liao, R. (2012). Application of a system dynamics approach for assessment of the impact of regulations on cleaner production in the electroplating industry in China. *Journal of Cleaner Production*, 20, 72–81. https://doi.org/10.1016/j.jclepro.2011.08.014

Ebrahimi, M., & Pilevar, N. (2021). System dynamics modeling and simulation to analyze the role of solar energy in secure access to sustainability. *Journal of Industrial Engineering International*, 17(1), 63-77. https://doi.org/10.30495/jiei.2021.1924887.1102

Esfahani, M. N., & Rasoulinezhad, E. (2017). Iran's trade policy of Asianization and De-Europeanization under sanctions. *Journal of Economic Studies*, 44, 552-567. https://doi.org/10.1108/JES-05-2016-0101

Fahimifard, S. M. (2020). Studying the effect of economic sanctions on Iran's environmental indexes (SVAR approach). *Journal of Econometric Modeling*, 18, 93-119. https://doi.org/10.22075/JEM.2020.21451.1504 (in Persian)

Farzanegan, M. R. (2013). Effects of international financial and energy sanctions on Iran’s informal economy. *The SAIS Review of International Affair*, 33(1), 13-36.

Farzanegan, M. R., & Fischer, S. (2021). Lifting of international sanctions and the shadow economy in Iran - A view from outer space. *Remote Sensing*, 13(22), 4620. https://doi.org/10.3390/rs13224620

Farzanegan, M. R., & Hayo, B. (2019). Sanctions and the shadow economy: empirical evidence from Iranian provinces. *Applied Economics Letters*, 26(6), 501-505. https://doi.org/10.1080/13504851.2018.1486981

Farzanegan, M. R., Khabbazan, M. M., & Sadeghi, H. (2016). Effects of Oil Sanctions on Iran's Economy and Household Welfare: New Evidence from a CGE Model. In *Economic Welfare and Inequality in Iran* (pp. 185-211). Palgrave Macmillan, New York.

Forrester, J. W., & Senge, P. M. (1980). Tests for building confidence in system dynamic models. *TIMS Studies Management Science*, 14, 209-228. Retrieved from: https://www.albany.edu/faculty/gpr/PAD724/724WebArticles/ForresterSengeValidation.pdf.

Gharehgozli, O. (2017). An estimation of the economic cost of recent sanctions on Iran using the synthetic control method. *Economics Letters*, 157, 141-144. https://doi.org/10.1016/j.econlet.2017.06.008

Haidar, J. I. (2017). Sanctions and export deflection: evidence from Iran. *Economic Policy*, 32(90), 319-355. https://doi.org/10.1093/epolic/eix002

Hosseini, S. M., Saifoddin, A., Shirmohammadi, R., & Aslani, A. (2019). Forecasting of CO2 emissions in Iran based on time series and regression analysis. *Energy Reports*, 5, 619-631. https://doi.org/10.1016/j.egyr.2019.05.004

Iran Energy Balance. (2017). *Energy Balance Sheet 2017, Energy Ministry of Iran*. Available online: https://www.isn.moe.gov.ir.

Jayanthakumaran, K., Verma, R., & Liu, Y. (2012). CO2 emissions, energy consumption, trade and income: a comparative analysis of China and India. *Energy Policy*, 42(c), 450-460. https://doi.org/10.1016/j.enpol.2011.12.010

Khabbazan, M. M., & Farzanegan, M. R. (2016). Household Welfare in Iran under Banking Sanctions: From Open Economy Toward Autarchy. In *Economic Welfare and Inequality in Iran* (pp. 213-232). Palgrave Macmillan, New York.

Kunche, A., & Mielczarek, B. (2021). Application of system dynamics modelling for evaluation of carbon mitigation strategies in cement industries: a comparative overview of the current state of the art. Energies, 14(5), 1464. https://doi.org/10.3390/en14051464

Labzovskii, L., Mak, H. W., Kenea, S. T. K., Rhee, J., Lashkari, A., Li, S., Goo, T., Oh, Y., & Byun, Y. (2019). What can we learn about effectiveness of carbon reduction policies from interannual variability of fossil fuel CO2 emissions in East Asia? *Environmental Science & Policy*, 96, 132-140. https://doi.org/10.1016/j.envsci.2019.03.011

Laudati, D., & Pesaran, M. H. (2021). Identifying the Effects of Sanctions on the Iranian Economy Using Newspaper Coverage. CESifo Working Paper No. 9217.

Lee, C. (2019). Decentralized allocation of emission permits by Nash data envelopment analysis in the coal-fired power market. *Journal of Environmental Management*, 241, 353-362. https://doi.org/10.1016/j.jenvman.2019.03.114

Li, J., Shi, X., Wu, H., & Liu, L. (2020). Trade-off between economic development and environmental governance in China: an analysis based on the effect of river chief system. *China Economic Review*, 60, 101403. https://doi.org/10.1016/j.chieco.2019.101403

Liu. X., Ma, s., Tian, J., Jia, N., & Li, G. (2015). A system dynamics approach to scenario analysis for urban passenger transport energy consumption and CO2 emissions: a case study of Beijing. *Energy Policy*, 85, 253–270. https://doi.org/10.1016/j.enpol.2015.06.007

Madani, K. (2020). How international economic sanctions harm the environment. *Earth's Future*, 8, e2020EF001829. https://doi.org/10.1029/2020EF001829

Madani, K. (2021). Have international sanctions impacted Iran's environment? *World*, 2, 231-252. https://doi.org/10.3390/world2020015

Malbon, E., & Parkhurst, J. (2022). System dynamics modelling and the use of evidence to inform policymaking. *Policy Studies*, (in press). https://doi.org/10.1080/01442872.2022.2080814

Mostafavi, S. M., Ghaemi Asl, M., & Hoseini, A. (2014). An investigate for causality relationship among Economic sanctions, Macroeconomic factors and environmental polluters in Iran. *Quarterly Journal of Quantitative Economics*, 11(1): 103-128. https://jqe.scu.ac.ir/article_11707.html?lang=en (In Persian)

Olivier, J. G., & Peters, J. A. (2020). *Trends in global CO2 and total greenhouse gas emissions, 2020 Report*. © PBL Netherlands Environmental Assessment Agency, The Hague, 2020 PBL publication number: 4331. Available at: https://www.pbl.nl/sites/default/files/downloads/pbl-2020-trends-in-global-CO2-and_total-greenhouse-gas-emissions-2020-report_4331.pdf.

Omri, A. (2013). CO2 emissions energy consumption and economic growth nexus in MENA countries: Evidence from simultaneous equations models. *Energy Economics*, 40, 657-664. https://doi.org/10.1016/j.eneco.2013.09.003

Pourkiaei, S. M., Pourfayaz, F., Shirmohammadia, R., Moosavi, S., & Khalilpoor, N. (2021). Potential, current status, and applications of renewable energy in energy sector of Iran: a review. *Renewable Energy Research Applications*, 2(1), 25-49. https://doi.org/10.22044/rera.2020.8841.1008

Proano, L., Sarmiento, A. T., Figueredo, M., & Cobo, M. (2020). Techno-economic evaluation of indirect carbonation for CO2 emissions capture in cement industry: a system dynamics approach. *Journal of Cleaner Production*, 263, 121457. https://doi.org/10.1016/j.jclepro.2020.121457

Rahmani, O., Rezania, Sh., Beiranvand pour, A., Aminpour, Sh., Soltani,M., Ghaderpour, Y., & Oryani, B. (2020). An overview of household energy consumption and carbon dioxide emissions in Iran. *Processes*, 8(8), 994. https://doi.org/10.3390/pr8080994

Saberpour, A., Akhavan Fard, M., & Masoud, G. (2021). Impact of sanctions on transfer of environmental technologies in international law with emphasis on Iran. *Medical Law Journal*, 15(56), 299-316. http://ijmedicallaw.ir/article-1-1310-en.html (In Persian)

Statistical Center of Iran (SCI). (2021). *Selected findings of the 2019 annual national accounting*. Available online: https://www.amar.org.ir/english.

Wang, S., Li, Q., Fang, Ch., & Zhou, Ch. (2016). The relationship between economic growth, energy consumption, and CO2 emissions: Empirical evidence from China. *Science of The Total Environment*, 542(A), 360-371. https://doi.org/10.1016/j.scitotenv.2015.10.027

Wasti, S. K. A., & Zaidi, S. W. (2020). An empirical investigation between CO2 emission, energy consumption, trade liberalization and economic growth: A case of Kuwait. *Journal of Building Engineering*, 28, 101-104. https://doi.org/10.1016/j.jobe.2019.101104

World Bank. (2021). *Iran's economic outlook*. Available online: http://www.worldbank.org/en/country/iran/publication/economic-outlook.

Wu, H., Hao, Y., & Ren, S. (2020). How do environmental regulation and environmental decentralization affect green total factor energy efficiency: evidence from China. *Energy Economics*, 91, 104880. https://doi.org/10.1016/j.eneco.2020.104880

Wu, H., Peng, D., & Wang, L. (2020). Model for sustainable development based on system dynamics and energy–economy–environment coordination: A case study of Beijing, China. *Energy Science &. Engineering*, 9, 828–842. https://doi.org/10.1002/ese3.837

Yang, H., Li, X., Ma, L., & Li, Z. (2021). Using system dynamics to analyse key factors influencing China's energy-related CO2 emissions and emission reduction scenarios. *Journal of Cleaner Production*, 320, 128811. https://doi.org/10.1016/j.jclepro.2021.128811

Yang, H., Ma, L., & Li, Z. (2020a). A method for analyzing energy-related carbon emissions and the structural changes: a case study of China from 2005 to 2015. *Energies*, 13, 2076. https://doi.org/10.3390/en13082076

Yang, J., Cai, W., Ma, M., Liu, C., Ma, X., Li, L., & Chen, X. (2020b). Driving forces of China's CO2 emissions from energy consumption based on Kaya-LMDI methods. *Science of The Total Environment*, 711, 134569. https://doi.org/10.1016/j.scitotenv.2019.134569

Ye, F., Xiong, X., Li, L., & Li, Y. (2021). Measuring the effectiveness of the Chinese certified emission reduction scheme in mitigating CO2 emissions: A system dynamics approach. *Journal of Cleaner Production*, 294, 125355. https://doi.org/10.1016/j.jclepro.2020.125355

Zamani, O., Farzanegan, M. R., Loy, J., & Einian, M. (2021). The impacts of energy sanctions on the black-market premium: evidence from Iran. *Economics Bulletin*, 41(2), 432-443. Available at: http://www.accessecon.com/Pubs/EB/2021/Volume41/EB-21-V41-I2-P38.pdf