Iranian Journal of Economic Studies, 13(2) 2024, 481-513

Shiraz University

Iranian Journal of Economic Studies

Journal homepage: ijes.shirazu.ac.ir

Green Paradox Test in Fiscal Decentralization Using Multi-Objective Optimization and Response Surface Methodology (RSM)

Ebrahim Anvari[a*], Elham Jafari[a], Hassan Farazmand[a], Amir Hossein Montazer Hojat[a]

a. Faculty of Economics and Social Sciences, Shahid Chamran University of Ahvaz, Ahvaz, Iran.

Article History

Received date: 12 March 2025
Revised date: 23 June 2025
Accepted date: 28 July 2025
Available online: 22 September 2025

JEL Classification

E62
H1
H77
O43
Q56

Keyword

Fiscal decentralization
Economic growth
Energy consumption
Revenue decentralization
Expenditure decentralization
Carbon Dioxide emissions

Abstract

In a situation where environmental degradation, extreme climatic events, energy consumption, and increasing carbon dioxide emissions have become major challenges, fiscal decentralization is recognized as an effective strategy to promote environmental sustainability. Fiscal decentralization is an integrated system of the management of revenue, expenditure, and related liabilities to lower levels of government. In the present study, RSM and seasonal data during the period 1996-2023 were used for multi-objective optimization. Two objective functions, carbon dioxide reduction and energy consumption, were also selected for optimization in two scenarios. The research variables also include revenue decentralization, expenditure decentralization, economic growth, urbanization rate, and industrialization. For optimization in both scenarios, 4 influential decision-making variables were selected and considered as optimization variables, and the goal was to reduce the two objective functions of carbon dioxide and energy consumption. In the first scenario, Important factors are the rate of urbanization, industrialization, and economic growth on the objective function of energy consumption and carbon dioxide. Also, the revenue decentralization parameter had the least impact on the objective functions of carbon dioxide and energy consumption. In the second scenario, the greatest impact on the objective function was economic growth and industrialization rate. Also, the least impact on the objective functions was the expenditure decentralization parameter. Therefore, in both scenarios, revenue decentralization and expenditure decentralization had a negligible and negative impact on carbon dioxide emissions, and therefore, a green paradox was not created in Iran.

Highlights

- This study seeks to test the Green paradox in financial deregulation using a multi-objective optimization and response surface methodology(RSM).
- In the present study, the response surface methodology has been used for multi-objective optimization(RSM).
- In both scenarios, decentralization of revenue and decentralization of expenditure had a negligible and negative impact on carbon dioxide emissions, and therefore, a green paradox has not been created in Iran.

∗ e.anvari@scu.ac.ir

DOI: 10.22099/ijes.2025.52689.2017

1. Introduction

Decentralization, in general, is the transfer of governance aspects from central government layers to local government layers. Decentralization involves the transfer of a wide range of powers, responsibilities, and resources from the central level to provincial levels as legal entities elected by popular vote and endowed with some degree of autonomy. Local governments consist of executive bodies with political legitimacy and administration. In addition to a certain decision-making power, the central sub-categories also have autonomy over expenditures, revenues, taxes, and budgets. Furthermore, the concept of decentralization is about reorganizing and reallocating relationships between different levels of governance to ultimately create greater coordination and cooperation between them. The interdependence they create requires structural and cultural changes at the central government level (OECD, 2019). Improved performance, increased equity, and economic growth are important outcomes of decentralization. Regional development is also managed more efficiently by local governments. Local government has great momentum in responding to the needs of people and residents due to its proximity to service recipients and the advantage of having detailed knowledge of the people's desires. With decentralization, deprived and less advantaged areas in the growth phase will have a more equitable allocation of urban services (Ji et al, 2020). One of the threats facing the world is environmental degradation as a result of excessive energy consumption and overexploitation of natural resources, such that carbon dioxide is now considered one of the most important factors in air pollution (Su et al., 2021). There are two approaches, upward competition and downward competition, regarding the impact of decentralization on energy consumption. In the first approach, the transfer of power from the central government to local institutions is expected to lead to a reduction in the consumption of non-renewable energy due to the imposition of restrictions on energy consumption by local institutions to improve environmental quality (Su et al., 2021). In this case, fiscal decentralization increases the revenues of provincial institutions. As a result, provincial institutions can use this opportunity to encourage companies to use clean technologies in production, and lower fossil energy consumption, and consequently, less pollution is produced (Wang et al., 2020). Directing public funds towards renewable energy solutions and environmental innovations, along with tax cuts for sustainable companies, is an effective policy. Implementing effective environmental policies can encourage local governments to invest in pollution treatment and prevention to shift the production process towards green and environmentally friendly production. As a result, strict environmental policies enable local governments to improve the environmental costs of economic recovery and coordinate economic and environmental goals. On the other hand, environmental protection costs create additional costs, increased burdens, and a new set of organizational challenges. Stringent environmental policies are a vital tool that can be used directly or indirectly to reduce environmental problems. The combination of strict environmental laws and strong institutions strengthens the driving force of environmental sustainability (Yıldız, 2025). In this approach, even governments support energy-intensive heavy industries to achieve the goal of increasing GDP growth rates. Thus, fiscal decentralization increases fossil fuel consumption (Su et al, 2021). Controlling environmental pollution through fiscal decentralization is beneficial, but it may lead to regional heterogeneity. Fiscal decentralization, by creating heterogeneity, can lead to the adoption of conflicting development strategies between developed and less developed regions. Fiscal decentralization requires local governments to strike the necessary balance between economic progress and environmental protection while simultaneously advancing the economy and improving living conditions. (Kuai et al., 2019). The increasing attention to the topic of fiscal decentralization can be traced to various causes such as increased welfare and efficiency in various sectors and ultimately higher economic growth. (Romero molina, 2018).

Given the spread of negative side effects of energy consumption, including global warming and its harmful effects on the environment and health of communities, it is necessary to implement policies to control it. One of the variables affecting air pollution and energy consumption that has recently attracted the attention of researchers is fiscal decentralization. Due to the importance of decentralization in economic issues, the need to examine the effects of fiscal decentralization on pollution in Iran is becoming more and more apparent. Therefore, the purpose of this research is to examine the green paradox test in fiscal decentralization in Iran. After an introduction to the theoretical foundations, research history and studies conducted, research method, model specification, and results, and finally, conclusions are presented.

2. Literature Review

With destruction and extreme weather events, fiscal decentralization has been seen as an effective strategy to improve environmental health. Fiscal decentralization is defined as a comprehensive system, a framework for delegating the authority to manage revenues, expenditures, and financial obligations to lower levels of government. In many countries around the world, fiscal decentralization has been proposed as one of the key policy mechanisms to promote local economic and social development (Xu, 2022). Martinsozquez & McNabb (2003) define decentralization as the transfer of authority, decision-making, and responsibility to local governments. They also show that there are two theories about fiscal decentralization. The first theory focuses on the benefits of economic efficiency and resource allocation at the domestic level. Oates's (1972) decentralization theorem suggests that proximity to residents, individuals, and institutions can have informational advantages. This approach can also lead to improved levels of efficiency, service delivery, and economic growth at the regional and national levels. Tiebout (1956) believes that decentralized powers lead to a better matching of goods and services than a centralized government system. Morgan (2002) argues that decentralization and greater delegation of political power lead to economic benefits. The second theory suggests that decentralization is a means of promoting and sustaining the development of markets (Martinez-Vazquez & McNabb, 2003). The existing evidence on the relationship between financial decentralization and the environment is mainly divided into two mechanisms: upward competition and downward competition. Within the framework of the upward competition mechanism, the first example has favorable consequences for the environment, suggesting that a decentralized fiscal system allows local governments to track polluting industries and, if necessary, transfer them to other countries using coercive means. Instead of reducing environmental restrictions, local governments impose stricter standards, which leads to improved environmental sustainability. It is this system of fiscal decentralization that allows local institutions to design more effective environmental policies, taking into account the specific conditions and characteristics of each region. The upward competition mechanism also proposes the hypothesis that local administration is more efficient than central government in providing public services without adverse consequences. In contrast, the race to the bottom model suggests that regional authorities may prioritize economic growth over environmental sustainability. Increased fiscal decentralization may lead to competition between regions and force local authorities to reduce environmental considerations in order to attract foreign investment, which could threaten environmental stability. These policies could attract investment to polluting, fossil-fuel-dependent industries, leading to environmental degradation. In line with the "race to the bottom" model, increased fiscal decentralization is seen as a key driver of environmental problems (Satrovic et al., 2025). Classical public finance theory assumes that financial assets play special roles in the economy under the fundamental functions of resource allocation, income distribution, wealth, and macroeconomic stabilization (Musgrave, 1959). According to this theory, a decentralized fiscal structure establishes a closer connection between regional administrations and citizens, which leads to a better understanding of the needs of society and ultimately enables the formulation of more effective spending policies for local public goods than the central government. The study of the relationship between fiscal decentralization and economic progress has received special attention from economists for the past three decades. Fiscal decentralization provides a context for achieving economic growth. Martinez-Vazquez & McNabb (2003) argue that from a theoretical perspective, the classical theory of fiscal decentralization does not support the concept of economic growth. The observed inverse relationship between fiscal decentralization and economic development may indicate that in reality, local institutions are not adequately responsive to the demands of the local community. This situation mainly occurs in cases where regional officials are not elected through popular elections. In general, fiscal decentralization is a tool to improve public sector efficiency, encourage competition among local entities in the provision of public services, and facilitate economic progress. The ultimate goal of this process is to optimize public sector performance, which will ultimately lead to sustainable economic development. Economic efficiency is improved through fiscal decentralization because provincial and local authorities have more accurate data and a more comprehensive understanding of local conditions than the central government. Traditional economic theorists have not provided a clear analytical framework to explain the direct causal relationship between fiscal decentralization and economic development. First, the decentralized financial system increases the accountability of local institutions to citizens' demands and highlights the key position of regional management in allocating public resources to provide local public services. Due to their proximity to citizens, local governments have the opportunity to reduce the costs of information collection and exchanges, which leads to the optimization of public spending. On the other hand, devolution of fiscal powers intensifies fiscal competition among local institutions. This mechanism plays a key role in aligning citizens' demands with policy directions. Fiscal competition also strengthens the accountability of local institutions, leading to a smaller government and reduced public spending (Buser, 2011). Fiscal decentralization can have significant impacts on the environment and carbon dioxide emissions. This section examines the impact of fiscal decentralization on carbon dioxide emissions, fiscal decentralization on environmental impacts, and the Hotelling model.

1.2. The Impact of Fiscal Decentralization on Carbon Dioxide Emissions

Many researchers have studied the relationship between fiscal decentralization and greenhouse gas emissions (Yang et al., 2020). Increasing local fiscal authority can play an effective role in pollution management and greenhouse gas reduction. Supporters of this view believe that this approach, in addition to strengthening local institutions, leads to better resource efficiency and a more accurate understanding of environmental issues and regional needs. Within the framework of a decentralized financial system, local institutions are able to simultaneously achieve economic growth and improve environmental conditions (Yang et al., 2020). Hao et al. (2020) believe that a decentralized financial system would have a detrimental effect on carbon dioxide emissions. The opposing view believes that such a policy would exacerbate carbon emissions and create a race to the bottom mechanism (Liu et al., 2019). Many researchers have considered fiscal decentralization as a viable option for reducing carbon dioxide emissions (Matheus et al., 2019). Decentralization of fiscal powers may lead to productive competition between regional administrations. By setting stricter environmental protection standards, it is possible to significantly reduce pollution in the affected areas. In practice, many central governments have in recent years delegated some of their environmental responsibilities to the local level. However, disagreements about the impact of fiscal decentralization on carbon emissions have intensified concerns (Chen & Chang, 2020). Proponents of this view argue that fiscal decentralization may lead to low competitiveness, where municipalities ignore environmental considerations in order to attract foreign investment and exacerbate greenhouse gas emissions. These contradictory findings can be explained by considering the quality of the human resource and the institutional framework (Ahmed et al., 2020).

2.2 Fiscal Decentralization and Environmental Impacts

Local governments in local geographic locations are closer to the people, which gives them an information advantage that allows them to deliver more efficient public services. Financial decentralization can encourage companies to develop environmental protection technology, thereby reducing the cost of environmental damage (Zhang et al., 2020). Fiscal decentralization can increase efficiency and improve environmental conditions (Liu et al., 2019) suggested that local government can take initiatives to improve public services that encourage companies to use cleaner production technologies and increase environmental protection. Comprehensive environmental protection policies can regulate organizational behavior and encourage the government to take responsibility for the environment, so that local governments can work together to improve environmental conditions and social welfare and compensate for efficiency losses as appropriate. However, fiscal decentralization lacks a deterrent mechanism that prevents local governments from considering cost savings when addressing environmental problems. Local governments can lower environmental monitoring standards to attract more companies to invest in local areas. Under the decentralization system, local governments improve local environmental standards, and polluting companies from developed areas can move to areas with low environmental standards. This phenomenon can ultimately lead to the deterioration of the environmental quality of the entire region (Zhang et al, 2020).

3.2 Hoteling model

This section examines the effects of different paths of carbon pricing (exogenously) within a closed economy. In the field of environmental policy, various solutions have been proposed to determine the price of carbon emissions, the most prominent of which is increasing taxes related to carbon emissions. To illustrate some of the underlying mechanisms in the impact of a fixed exogenous carbon tax pathway on the use of non-renewable resources, we use a simple resource extraction model. Subsidies are used as a substitute for the price of greenhouse gas emissions and to reduce these emissions. Hence, these subsidies are generally not optimal and may reflect reactions from fossil fuel reserve owners that were not considered during the decision-making process. Supporting these technologies in the form of research and development subsidies reduces the cost of alternative energy sources or as a subsidy per unit of alternative energy used. This section examines the effects of different paths of carbon pricing (exogenously) within a closed economy. In the field of environmental policy, various solutions have been proposed to determine the price of carbon emissions, the most prominent of which is increasing taxes related to carbon emissions.

$$\hat{P} = \frac{\overset{0}{P}(t)}{P(t)} = r0 \quad (1)$$

There is a moment when the economy shifts away from fossil fuels as a support. τ(t) is the carbon emission tax (one unit of resource use creates one emission unit). c(X(t)) is the unit extraction and is an incremental function of the cumulative extraction amount X(t). Extraction cannot exceed the initial resource stock, X¯. With D(•) > 0. In addition to the non-renewable resource, a clean and completely technologically switchable energy alternative may be available at a fixed marginal cost b, such that D(•) = x(t) = 0 for p(t) > b. We denote the moment of switching to the previous energy source by tb, such that p(tb) = b The initial resource price (0) p and tb are determined immediately by the condition that the resource stock runs out before the change as a supporting factor.

$$\int_0^{t_b} D(P(0)\overset{rt}{e})\, dt = \bar{X} \tag{2}$$

And the condition that at tb, the price of b as a support is equal to the scarcity rent:

$$P(0)\overset{rt_b}{e} = b. \tag{3}$$

What is the impact on greenhouse gas emissions of a policy that reduces the marginal cost of technology as a clean supporter (e.g., as a result of R&D subsidies for alternative energy technologies)? With the initial resource price unchanged (0) p, this indicates that some resources remain unexploited, which forces resource owners to supply more at any point in time, thereby lowering the equilibrium resource price. Hence, reducing the marginal cost of the supporting agent increases extraction at any point while the pollutant source is still in use. The phenomenon of weak environmental paradox is observed (Gerlagh, 2011). This is while the growth rate of final losses is considered to be lower than the interest rate, Gerlagh (2011) It shows that within the framework of the basic Hotelling model, it proves that reducing marginal support costs leads to an increase in the net present value of environmental damages, thus creating a strong green paradox. Van der Ploeg & Withagen (2012b) add to the Hotelling model by adding (linear) equity-dependent extraction costs and isolating the damage from atmospheric carbon dioxide stocks through a quadratic damage function. The marginal costs of the supporting technology, whether the resource reserves are completely exhausted (Hotelling model) or not (Hoel model). In the case of full utilization, they confirm the Gerlach result. The weak and strong Green paradox occurs in response to the reduction of the marginal cost of the supporting technology.

4.2 Knowledge gap

Carbon dioxide emissions as an indicator of environmental pollution are caused by several factors. One of the most important of these factors is energy consumption. Energy consumption causes the emission of a large amount of greenhouse gases and global warming. In fact, energy consumption and the spread of its polluting effects cause environmental degradation and the health of societies. Therefore, energy policy and environmental policy are closely related. In fact, if the incomplete design of environmental policy leads to an unwanted increase in carbon dioxide emissions, this phenomenon is called the green paradox. Therefore, controlling carbon dioxide emissions as an indicator of environmental pollution is essential for achieving sustainable economic development. Therefore, implementing efficient and correct policies to manage and reduce energy consumption, recognizing the factors affecting it, and being aware of how these variables interact and influence, which have recently been examined in empirical studies, is fiscal decentralization. The fiscal decentralization index has attracted the attention of many economists and policymakers and in recent years has been on the agenda of research institutions in the field of energy economics and environment due to global warming and carbon dioxide emissions following the increase in energy consumption, because local governments implement more effective policies and planning to control energy consumption and carbon dioxide emissions than central governments due to their knowledge of the environment. However, empirical studies on the effect of fiscal decentralization on energy consumption have not reached a consensus, because in some studies, fiscal decentralization has led to an increase in energy consumption due to the expansion of competition between local institutions to attract investors for economic growth, and in some other cases, energy consumption has decreased with the increase in the degree of fiscal decentralization due to improved efficiency in consumption and efficient actions of local institutions.

Despite many studies conducted in the field of fiscal decentralization, little attention has been paid to the environmental consequences of fiscal decentralization in Iran, and few studies have been conducted in this field. Also, no study has been conducted in Iran so far on the investigation of the green paradox using the multi-objective optimization and response surface methodology (RSM). Therefore, due to the issue of fiscal decentralization in regional sustainable development and the increase in pollutant emissions, the importance of investigating the effects of fiscal decentralization on energy consumption and pollution in Iranian provinces is becoming more and more apparent. Therefore, this research is trying to empirically evaluate the impact of various fiscal decentralization indicators (including fiscal decentralization of income and fiscal decentralization of expenditures) on energy consumption and environmental impacts in Iranian provinces using modern econometric tools. Therefore, the difference between this study and previous studies, in addition to the innovation of the subject, is the use of the response surface methodology to investigate the green paradox. This is a point that has been addressed in a few studies.

5.2 Previous studies

Malik et al (2006) examined the relationship between fiscal decentralization and economic growth in Pakistan, based on time series data for the period 1972 to 2005, using OLS and first-order moving averages. The results showed that fiscal decentralization was a driver of economic growth.

Pansuwan (2009) conducted a study on industrial decentralization and industrialization policies in Thailand. Based on the results, the government has recently placed greater emphasis on rural industrial development and stated that rural industries should correct this geographical imbalance of industrialization in the country.

Comola & Mello (2010) In a study examining fiscal decentralization and urbanization in Indonesia, used a dataset of local governments for 1996 and 2005 to estimate the effect of decentralization. The findings showed that increasing the minimum wage was associated with faster population growth in urban areas, while it did not affect rural population growth.

Jafari Samimi et al (2010) conducted a study to investigate the relationship between fiscal decentralization and economic growth in Iranian provinces during the period 2001 to 2007 using the panel data method. The results showed that fiscal decentralization to provincial levels has promoted economic growth.

He (2015) investigated the impact of fiscal decentralization on environmental pollution control in China using provincial panel data from 1995 to 2010 using the GMM method. The results showed that fiscal decentralization had a positive and significant effect on pollution abatement costs and pollutant discharge costs.

Zhang et al. (2017) used panel data from 29 provinces in China during the period 1995-2012 to examine the impact of decentralization policies on the performance mechanisms of environmental policies. The results showed that environmental policies can reduce carbon emissions. However, decentralization policies significantly increase carbon emissions. The impact of decentralization also varies across regions.

Wang & Gao (2018) examined fiscal decentralization and industrial structure upgrading based on evidence based on data from 2002 to 2015. The results showed that the reform of county-level administrations promoted local governments and fiscal decentralization promoted industrial upgrading.

Khanzadi et al. (2019) analyze the effects of fiscal decentralization and environmental consequences in Iranian provinces during the period 2005-2015. The results of estimating the models using the generalized moments method showed that revenue decentralization had a negative and significant relationship and cost decentralization had a positive and significant relationship with pollution emissions.

Wang et al. (2020) analyzed the effects of fiscal decentralization and industrial structure on energy efficiency and consumption in 30 administrative and executive regions of China during the period 1997-2017. They used a space camera model to examine the effects of fiscal decentralization on energy efficiency and consumption. The results showed that fiscal decentralization had a positive effect on energy efficiency in eastern and central China. Fiscal decentralization also had a significant negative effect on energy consumption and environmental degradation.

Cheng et al. (2020) estimated an equation to combine fiscal decentralization and carbon dioxide emissions and examine the impact of fiscal decentralization on carbon dioxide emissions in China using a dynamic panel regression model and cross-provincial data from 1997 to 2015. The results showed that the relationship between fiscal decentralization and carbon dioxide emissions is nonlinear.

Elheddad et al. (2020) conducted a study to investigate the relationship between energy consumption and fiscal decentralization and the importance of urbanization in Chinese provinces during the period 2006–2015. To this end, this study used multiple panel data analysis and quantitative panel regression to analyze this effect. According to the results, financial decentralization has a nonlinear relationship with energy consumption.

Wang et al. (2021) examined the impact of fiscal decentralization, green technology innovation, and air pollution for 30 provinces in China during the period 2003 to 2018 using a space camera model. The results showed that decentralization can exacerbate air pollution. Also, green technology innovation did not play a positive role in reducing pollution emissions.

Salem & Jabbari (2021) investigated the nonlinear effect of fiscal decentralization on energy consumption in Iranian provinces using a quantile panel model during the period 2006-2019. The results of this study showed that fiscal decentralization had a nonlinear inverted U-shaped relationship with energy consumption.

Udeagha & Breitenbach (2023) In a study examined the relationship between fiscal decentralization and carbon dioxide emissions in South Africa from 1960 to 2020, using the dynamic ARDL method. The results showed that fiscal decentralization reduces carbon dioxide emissions.

Anvari et al. (2024) studied the prediction of fiscal decentralization from two dimensions of expenditure and revenue, considering energy consumption and environmental impacts, using hybrid intelligent models with optimization algorithms in Iran during the period 1996-2022. The results showed that revenue decentralization had a better overall performance compared to the expenditure decentralization model due to the lowest RMSE, MAE error values, and the highest R-value. Also, the value of the R statistic and the results of the optimization combination model (GPA) and the neural simulator model (GAPSO) showed that revenue decentralization had the best performance compared to the expenditure decentralization model.

Gao et al. (2025) examine the impact of financial decentralization and green innovation on facilitating the transition to a low-carbon economy in high-emission companies from 2008 to 2022. The research results show that fiscal decentralization significantly facilitates the transition to a low-carbon economy in polluting industrial companies.

Satrovic et al. (2025) examine the effect of fiscal decentralization on environmental sustainability in selected European countries from 1995 to 2020 using the momentum quantile regression method. The results showed that positively affects environmental sustainability through stricter environmental policies.

3. The Study Model

In this research, the multi-objective and response surface optimization (RSM) method has been used to examine the Green paradox test in financial decentralization.

1.3. Dynamic optimization and optimal control theory

Optimal control theory is a method for solving dynamic optimization problems that emphasize one or more control variables as a dynamic optimization tool. Therefore, unlike the calculus of changes, which aims to find the optimal time path for the state variable, optimal control theory aims to determine the optimal time path for the control variable. Of course, when the optimal control path is found, the optimal state path corresponding to can also be obtained. The paths are obtained in a similar process (Pindyck, 1973).

2.3. Principles and Methods of Control Theory

Now consider the simplest case of dynamic optimization and the concepts related to optimal control. Suppose we want to choose the value of and in the time interval such that it maximizes the following problem:

$$MaxV = \int_{t0}^{T} F(u(t),t)dt\,, u(t) \in [u0,u1] \quad (4)$$

Here are the initial and final times that are known. Now the question is how to choose the value to maximize the problem (4). In other words, we are looking for the optimal time path. The condition that it can maximize (4) is:

$$F(u(s),s) \leq F(u*(s),s)\ s \in [t0,t1] \quad (5)$$

Condition (5) states that if we want the integral (4) to be maximized, the value of the function under the integral must be maximized at every instant of time. In other words, if at every instant of time, u^* can maximize$F$, then its sum, shown in (4), will also be maximized.

3.3. Static optimization

In static optimization, we have the following problem to maximize a function of one variable $F(X)$:

$$MaxF(X), X \in I \quad (6)$$

where $I = [X1, X2]$ The necessary conditions $X * \in I$ to maximize Problem 6 are stated as follows:

$$F'(X*)(X - X*) \leq 0 \text{or} F'(X*)X \leq F'(X*)X* \quad (7)$$

The above condition can be called the maximum principle.

We can also write the following condition for any concave function:

$$F(X) \leq F(X*) + F'(X*)(X - X*) \quad (8)$$

It is obvious that if can maximize $F(X)$, then is $F'(X*)(X-X*)$ non-positive according to condition (7) and therefore will be $F(X) \leq F(X*)$ a necessary and sufficient condition for $X*$ to maximize the function F (Soori, 2006).

4.3. Response Surface Method (RSM)

Response Surface Methodology (RSM) is a set of statistical and mathematical methods that are very useful for modeling and analyzing problems in which the response variable is affected by several independent variables, and its goal is to optimize the response variables. The response surface methodology is a useful tool for describing quality indicators during a process. In this process, the response parameter is evaluated on a fixed scale. In most practical problems, more than one factor is involved in the quality and performance of a product, and these factors must be investigated. In response to surface optimization, input variables are defined as independent variables, and the effect of these variables on output (dependent) variables is studied. The most important advantage of response surface is the reduction of the number of experiments to evaluate multiple parameters and their interrelationships (Kleijnen, 2015).

4. Empirical Results

1.4. Solving the model and adjusting the coefficients

According to the research history described, this study used the Green Paradox test in financial decentralization in Iran according to the model (Song et al, 2023).

$$Min\ \mathrm{Cd}_t = \beta_0 + \beta_1 \mathrm{Id}_t + \beta_2 ID_t + \beta_3 Ur_t + \beta_4 EG_t + U_t \quad (9)$$

$$Min\ EC_t = \beta_0 + \beta_1 \mathrm{Id}_t + \beta_2 ID_t + \beta_3 Ur_t + \beta_4 EG_t + U_t \quad (10)$$

$$Min\ \mathrm{Cd}_t = \beta_0 + \beta_1 \mathrm{Sd}_t + \beta_2 ID_t + \beta_3 Ur_t + \beta_4 EG_t + U_t \quad (11)$$

$$Min\ EC_t = \beta_0 + \beta_1 \mathrm{Sd}_t + \beta_2 ID_t + \beta_3 Ur_t + \beta_4 EG_t + U_t \quad (12)$$

Ec stands for energy consumption, EG for economic growth, In for industrialization, Ur for urbanization rate, Id for renenue decentralization, Sd for expenditure decentralization, and Cd for carbon dioxide. The statistical population of this study includes seasonal data from 1996-2023 for 31 provinces of the country. Statistics and information related to the provinces have been collected from the Statistical Yearbook of the Statistical Center of Iran. Matlab software has been used to analyze the data.

To calculate the revenue decentralization variable, the ratio of provincial revenue to total provincial expenditures (sum of expenditure credits and acquisition of capital assets) was used. Expenditure decentralization also includes the ratio of each provinces development credits to the country's total development budget.

To calculate the carbon dioxide variable, the fuel-based carbon emission model was used according to the following equation.

$$CO_2 = \Sigma A_{it} CCF_{it} HE_{it} COF_{it} (\frac{44}{12})$$

In the above relationship, A is the consumption of each fuel, CCF is the carbon content, HE is the calorific value, COF is the carbon oxidation and the weight ratio of molecules to carbon. The urbanization rate is obtained by dividing the urban population of each province by the total population of the province. The energy consumption variable, this variable includes gasoline, kerosene, gas oil, fuel oil, electricity and natural gas, is calculated in terms of the physical unit of each carrier. In order to scale the energy units (petajoules), the conversion factor related to each carrier, according to the energy balance (2020), has been used. The economic growth variable. In this research, the added value of each province is considered as economic growth.

2.4. Multi-objective optimization and response surface methodology (RSM) for optimal control

In this study, two scenarios have been considered for optimization according to Table (1).

Table (1). Introduction to optimization scenario

Scenarios		Objective functions		Decision-making variables		
1	Carbon dioxide	Energy consumption	Revenue decentralization	Industrialization	Urbanization rate	Economic growth
2	Carbon dioxide	Energy consumption	Decentralization expenditure	Industrialization	Urbanization rate	Economic growth

Source: *Research calculations*

In Table (1), the objective functions of the two scenarios and decision variables are introduced.

The multi-objective optimization of this research was carried out using the RSM method. Using this method, the most optimal values of the objective functions and optimization variables are ultimately extracted. For optimization in both scenarios, 4 influential decision-making variables are selected and considered as optimization variables. Two objective functions of carbon dioxide reduction and energy consumption were also selected for optimization in two scenarios, and the goal of controlling each of them is optimization.

Table (2) introduces the optimization variables of scenario (1) and their ranges.

Table (2). Optimization variables of scenario (1) and their ranges

Factor	Name	Lower limit	Upper limit
A	Economic growth	-0/99	2864/29124
B	Industrialization	-0/99	341102/7383
C	Urbanization rate	-0/99	2007157/708
D	Revenue decentralization	-1	7454842257

Source: *Research calculations*

Table (2) introduces the optimization variables of scenario (1) and their upper and lower bounds.

Table (3) introduces the optimization variables of scenario (2) and their ranges

Table (3). Optimization variables of scenario (2) and their ranges.

Factor	Name	Lower limit	Upper limit
A	Economic growth	-0/99	2864/29124
B	Industrialization	-0/99	341102/7383
C	Urbanization rate	-0/99	2007157/708
D	Expenditure Decentralization	-1	4285899079797050000

Source: *Research calculations*

3.4. Results of Scenario (1)

Tables (4) and (5) present the results of the most optimal solution obtained from the RSM method for the decision variables and scenario objective functions. This response was extracted after screening using the multi-objective optimization method.

Table (4). Optimal value of decision variables for scenario (1)

Solution	Economic growth	Industrialization	Urbanization rate	Revenue decentralization	Composite Desirability

1	-0/522986	234376	2691/691	3296026	1

Source: *Research calculations*

Table (4) presents the optimal values of decision-making variables for scenario (1).

Table (5). Optimal value of objective functions of scenario (1)

Response	Goal	The optimal value	Upper
Energy consumption	Minimum	-1/001	1735333
Carbon dioxide	Minimum	-0/99997	88377

Source: *Research calculations*

Table (5) presents the optimal values of decision-making variables for scenario (1).

Table (6) presents the optimality limit with two ranges for the optimization objective functions.

Table (6). Optimality limit

Response	Goal	Lower limit	Upper limit
Energy consumption	Minimum	-0/674	25/1578
Carbon dioxide	Minimum	-0/866	13/5762

Source: *Research calculations*

In the following, the regression equation of the two target functions of carbon dioxide and energy consumption of scenario (1) has been calculated in equations (13) and (14). Regression analysis is a statistical process for estimating relationships between variables. It involves many techniques for modeling and analyzing specific and unique variables, focusing on the relationship between the dependent variable and one or more independent variables. Optimization helps to determine how the value of the dependent variable changes with each of the independent variables changing while the other independent variables are held constant. In general, regression analysis is also used to identify the relationship between the independent and dependent variables and the shape of these relationships.

$$Ec=-39+640EG-0/02\ In +15/98Ur+0/00009Id +0/000000In^*\ In -0/00157In^*\ Ur \quad (13)$$

$$Cd=337-1279\ EG-2\ In+ 323/1\ Ur-0/0002Id +0/000007+ In^*\ In -0/0310In^*\ Ur \quad (14)$$

In equations (13) and (14), Ec is energy consumption, EG is economic growth, In is industrialization, Ur is urbanization rate, Id is income decentralization, and Cd is carbon dioxide.

In Figure (1), the effect of design parameters on objective functions has been examined. The most influential design parameter is the rate of urbanization, industrialization, and economic growth, and the income decentralization parameter has the least effect on objective functions.

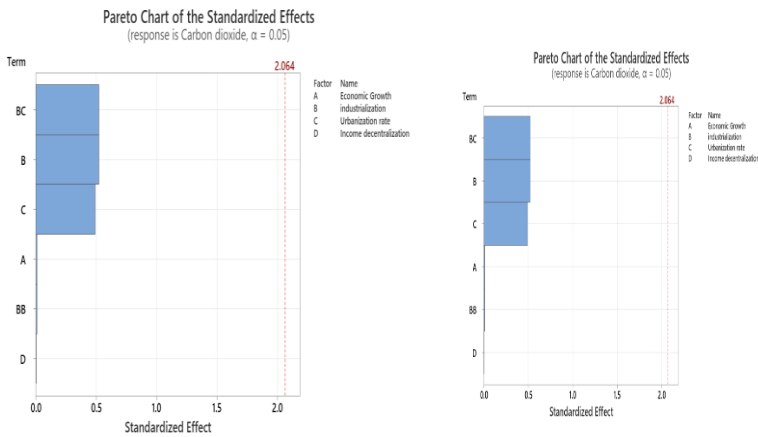
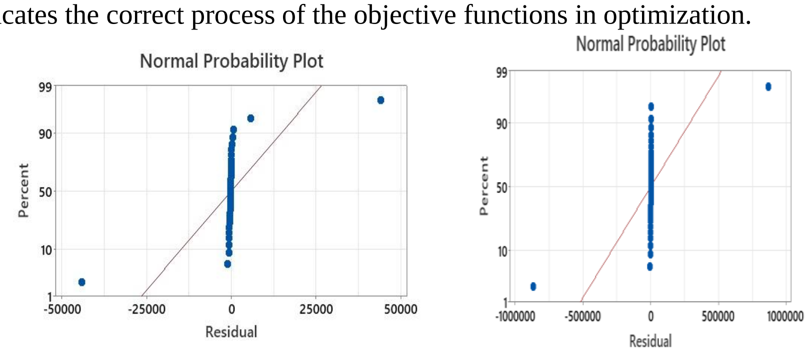


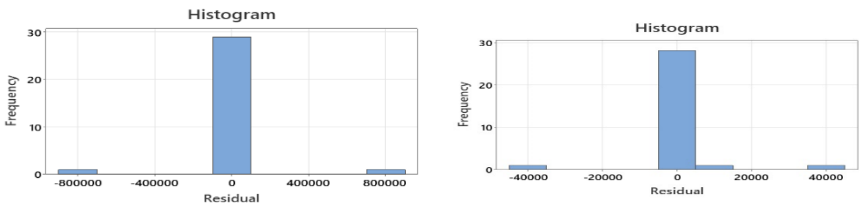
Figure (1). The effect of design parameters on objective functions.
Source: *Research calculations*

Figure (2) shows the optimization process of two objective functions, including a normality diagram. The closer the points on the diagram are to the bisector line, the more the residuals follow the normal distribution, which indicates the correct process of the objective functions in optimization.



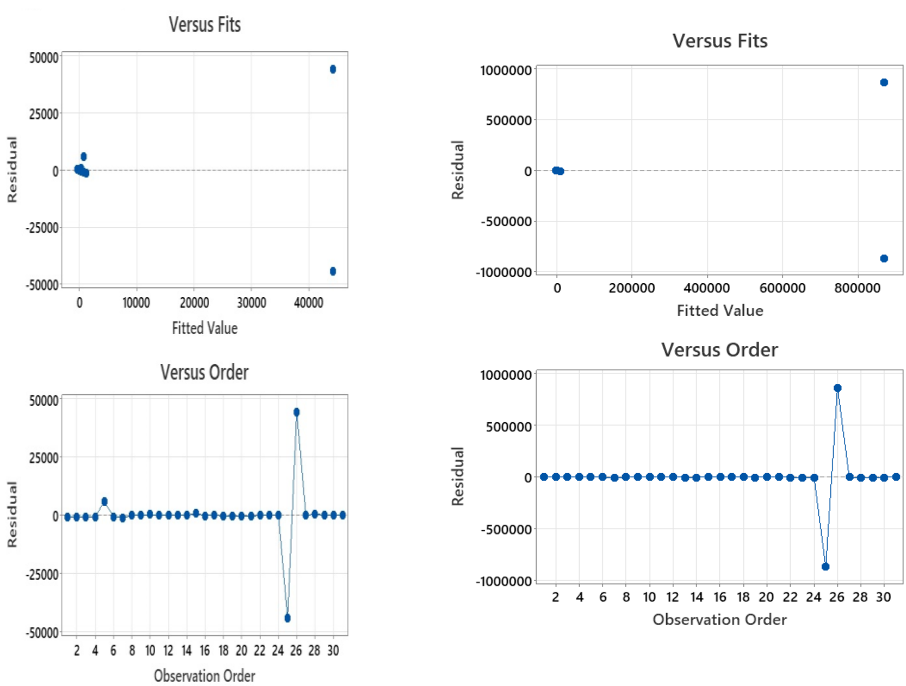
Energy consumption Carbon dioxide
Figure (2). Normality diagram of objective functions.
Source: *Research calculations*

Figure (3) shows a histogram of the optimization process. In this graph, each axis represents information from the data. The height of each column represents the frequency of each category in the available data. This chart shows the frequency or percentage of each class in the form of a column. Also, by using a histogram and drawing a normal distribution curve, one can find out the shape of the distribution (normality, skewness, and kurtosis) of the variable in question.



Carbon dioxideEnergy consumption
Figure (3). Histogram diagram of objective functions.
Source: *Research calculations*

Figure (4) shows the residual value and order of the optimization process of the two objective functions, and no abnormal behavior is seen in the results.



Energy consumption Carbon dioxide
Figure (4) Objective function order diagram

Source: *Research calculations*

In the chart, the Versus Fits Residual section shows the residuals versus the fitted values. The residuals of all the data are plotted against the objective functions, which are all located around the objective function value, so the points are still scattered around the zero horizontal line and no specific pattern is observed in the distribution of the points, indicating that there is no specific correlation between the residuals and the fitted values. The Residual Versus Fits chart also shows the residuals versus the order of observations. The purpose of this chart is to examine the independence of the residuals and identify any temporal patterns. Accordingly, the general dispersion of points in the charts indicates the absence of a specific pattern and the independence of the residuals.

Figure (5) shows the impact of decision-making variables on the carbon dioxide objective function. According to the results, the greatest impact on the objective function was the urbanization rate and industrialization rate, which resulted in a decrease in the growth of carbon dioxide. Revenue decentralization has a very low and negative impact on carbon dioxide emissions, which appears to have been created in each province through measures such as capital taxes, greater monitoring, and control of different levels of pollution. In other words, the investments made and the revenue sources earned in each province have reduced carbon dioxide emissions and pollution. Given that revenue decentralization has had a negligible and negative impact on carbon dioxide emissions, the green paradox phenomenon has not been created.

The urbanization rate also has a negative relationship with carbon dioxide emissions as an indicator of environmental pollution. It seems that with the increase in the relative density of the urban population, pollution decreases due to the demand for public transportation in the provinces. Economic growth also hurts carbon dioxide emissions. It seems that with increasing economic growth, the economic structure in the provinces has shifted towards information-based industries and services, and awareness about carbon dioxide emissions and the environment has increased, and more beneficial environmental laws have been enacted, leading to a reduction in pollution emissions.

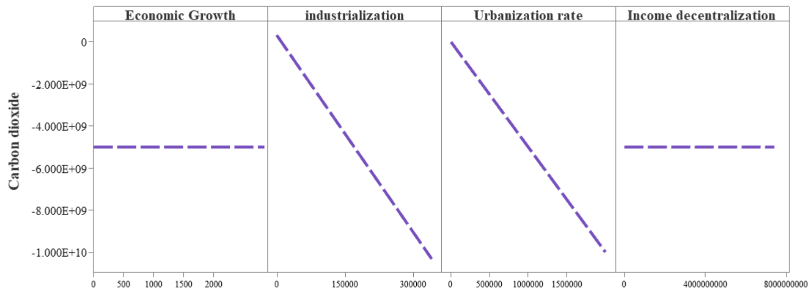


Figure (5). The impact of decision-making variables on carbon dioxide
Source: *Research calculations*

Figure (6) shows the impact of decision-making variables on the energy consumption objective function. As the results show, the urbanization rate and industrialization rate have the greatest impact on the energy consumption objective function, leading to a decrease in the growth of energy consumption.

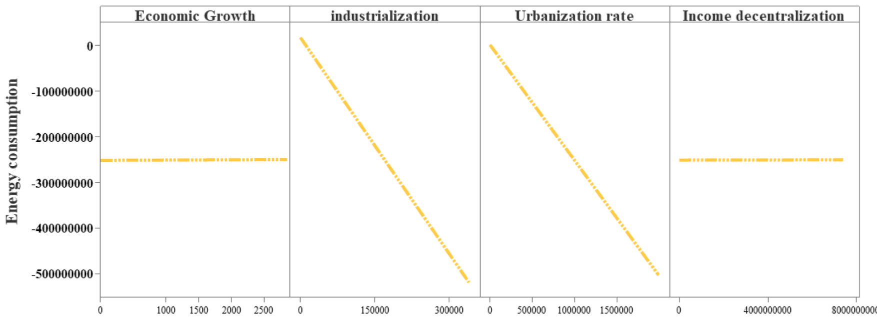


Figure (6). The impact of decision-making variables on energy consumption
Source: *Research calculations*

According to the results, the greatest impact on the objective function was the urbanization rate and industrialization rate, which led to a decrease in the growth rate of energy consumption. Revenue decentralization has a very low and negative impact on energy consumption, which appears to have been achieved in each province through measures such as capital taxes, greater oversight, and control over different levels of energy consumption. In other words, the investments made and revenue sources earned in each province have reduced energy consumption and pollution. The urbanization rate also has a negative relationship with energy consumption. It seems that as the relative density of the urban population increases, pollution and energy consumption decrease due to the demand for public transportation in the provinces. Economic growth has also hurt energy consumption. It seems that with increasing economic growth, the economic structure in the provinces has shifted towards information industries and services, awareness about energy consumption and the environment has increased, and more beneficial environmental laws have been enacted, leading to a reduction in energy consumption. Industrialization also harms energy consumption. With the advancement of technology and industrialization, production waste, environmental damage, and energy consumption in the provinces have decreased. Figure (7) shows the contour of the impact of decision-making variables on carbon dioxide. As the results show, simultaneous control of the two parameters of urbanization and industrialization had the greatest impact on carbon dioxide.

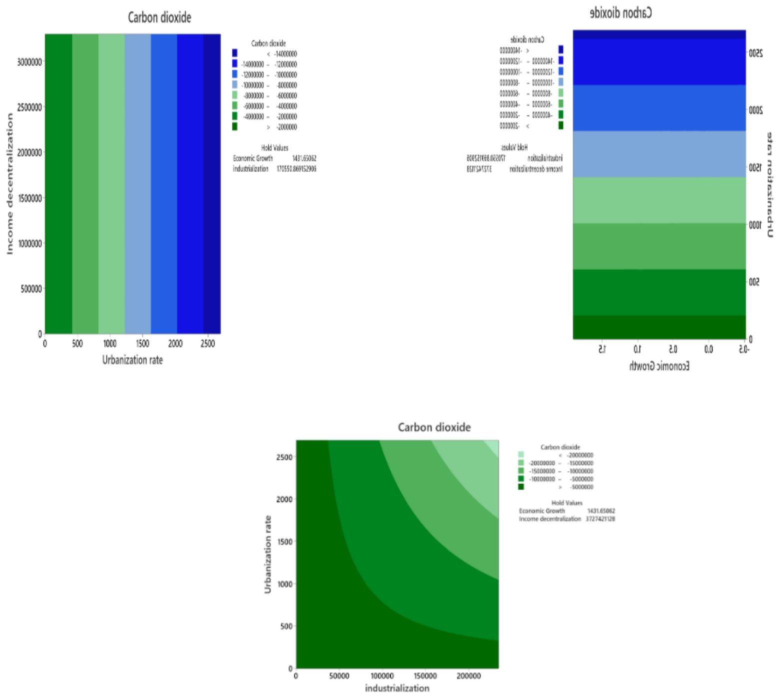
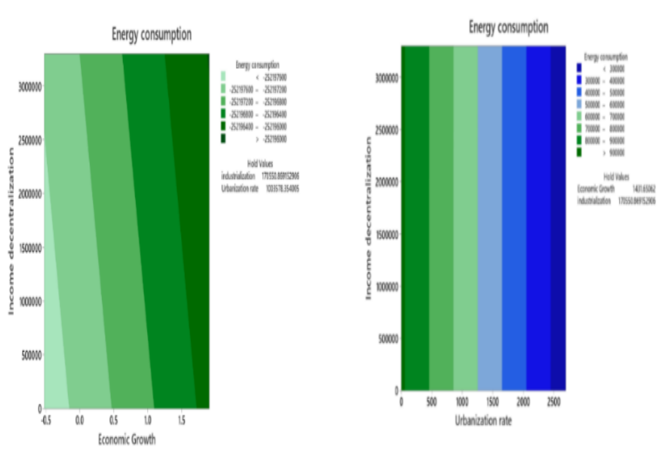


Figure (7). Contour of the impact of decision variables on carbon dioxid
Surce: *Research calculations*

Figure (8) shows the contour of the impact of decision-making variables on energy consumption. As the results show, the simultaneous change of the three parameters of urbanization, industrialization, and economic growth has the greatest impact on energy consumption.



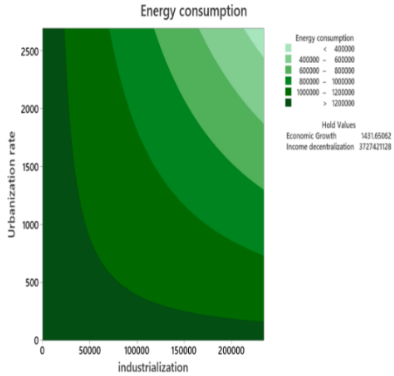


Figure (8). Contour of the impact of decision-making variables on energy consumption
Source: *Research calculations*

4.4. Results of Scenario (2)

Tables (7) and (8) present the results of the most optimal solution obtained from the RSM method for the decision variables and objective functions of scenario (2). This response was extracted after screening from the multi-objective optimization method.

Table (7). Optimal value of decision variables of scenario (2)

Solution	Economic growth	Industrialization	Urbanization rate	expenditure Decentralization	Composite Desirability
1	0/0454545	0/783410	-0/151779	48/0280	0/662835

Source: *Research calculations*

In Table (7), the optimal value of decision variables for scenario (2) is presented.

Table (8). Optimal value of objective functions of scenario (2)

Response	Goal	The optimal value	Upper
Energy consumption	Minimum	-0/647664	0/281
Carbon dioxide	Minimum	-0/910784	849/829

Source: *Research calculations*

In Table (8), the optimal value of the objective functions of scenario (2) is introduced.

Table (9) presents the optimality limits of two ranges for the optimization objective functions.

Table (9). Optimality limit

Response	Goal	Lower limit	Upper limit
Energy consumption	Minimum	-0/9709724	27/57813
Carbon dioxide	Minimum	-0/84124	4/37764417

Source: *Research calculations*

In the following, the regression equation of two objective functions of carbon dioxide and energy consumption of scenario (2) is calculated in relation to (15) and (16).

$$Cd=-1329+814\,EG+2142\,In*In+0/0001Sd \quad (15)$$
$$Ec=2810711+269047EG-2541844In*In+0/0002Sd \quad (16)$$

Figure (9) shows the impact of design parameters on objective functions. The most influential parameters are economic growth and industrialization, while the least influential parameters are expenditure decentralization and urbanization rate. expenditure decentralization has had a very low and negative impact on carbon dioxide emissions. It seems that provinces, given government constraints on budget allocation, have focused more on provincial development spending and current pollution abatement spending has been lower. Given that expenditure decentralization has had a negligible and negative impact on carbon dioxide emissions, the phenomenon of a green paradox has not been created.

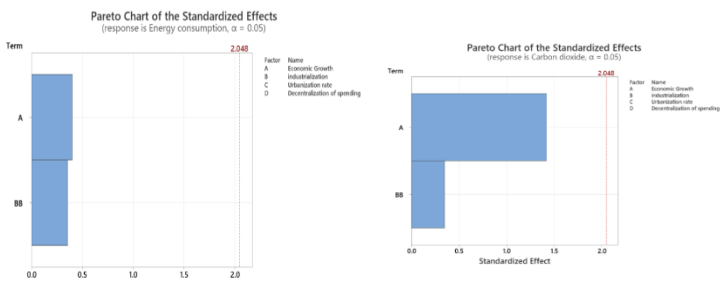
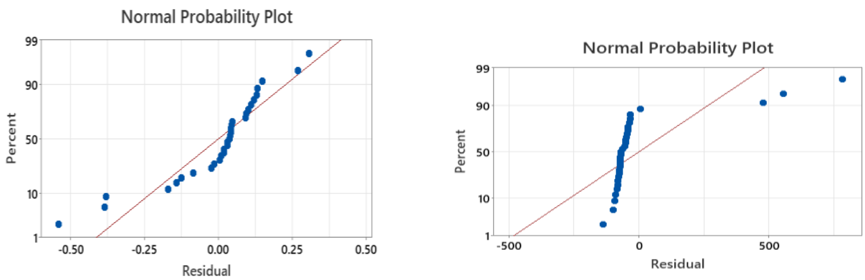


Figure (9). Effect of design parameters on objective functions.
Source: *Research calculations*

Figure (10) shows the optimization process of two objective functions including a normality diagram. The closer the points of the diagram are to the bisector line, the more the residuals follow the normal distribution, which results in the correct process of the objective functions during optimization.

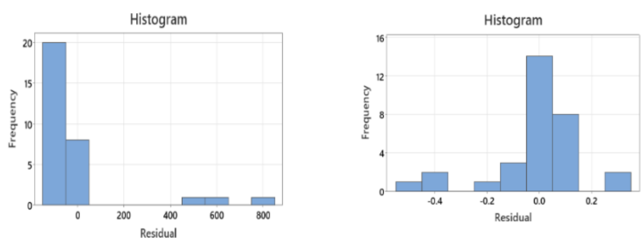


Carbon dioxideEnergy consumption

Figure (10). Normality diagram of objective functions.

Source: *Research calculations*

Figure (11) shows the histogram of the optimization process for scenario (2).

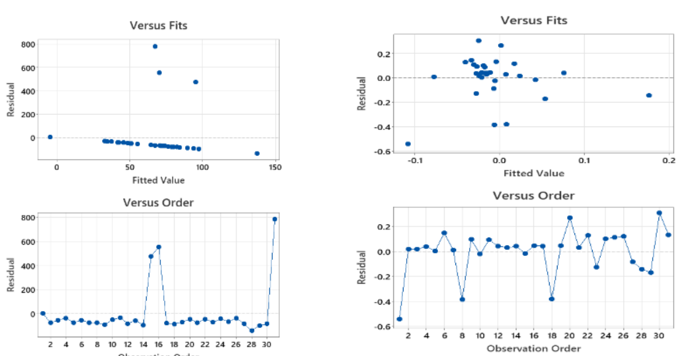


Energy consumptionCarbon dioxide

Figure (11). Histogram diagram of objective functions.

Source: *Research calculations*

Figure (12) shows the residual value and order of the optimization process of the two objective functions of scenario (2). According to the results, there was no abnormal behavior in the optimization.



Energy consumption Carbon dioxide

Figure (12). Objective function order diagram
Source: *Research calculations*

The Versus Fits Residual section shows the residuals versus the fitted values. The residuals of all data are plotted against the objective functions, which are all located around the objective function value. The points are still scattered around the zero horizontal line, and no specific pattern is observed in the distribution of points, indicating the absence of a specific correlation between the residuals and the fitted values. The Residual Versus Fits plot also shows the residuals versus the order of the observations. The purpose of this plot is to examine the independence of the residuals and identify any temporal patterns. Accordingly, the general scatter of points in the plots indicates the absence of a specific pattern and the independence of the residuals.

Figure (13) shows the impact of decision-making variables on the carbon dioxide objective function. As the results show, economic growth and industrialization rate have the greatest impact on the objective function.

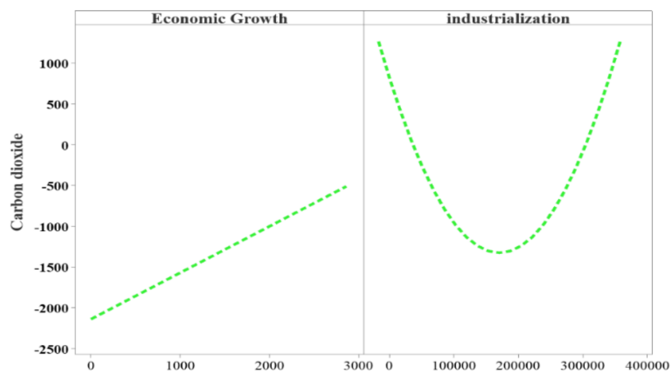


Figure (13). The impact of decision variables on carbon dioxide
Source: *Research calculations*

The effects of decentralization on pollution are shown both directly and indirectly. With fiscal decentralization, regional governments pay less attention to environmental policies due to competition for investment and higher economic growth. In other words, to evaluate and promote local governments, the central government uses the local economic growth rate and collected revenues. Therefore, it is natural that local authorities in the provinces put all investment in to increasing economic growth instead of pollution control. Therefore, economic growth has a positive effect on environmental quality. According to Figure (13), industrialization initially leads societies towards other values by decentralizing finance and achieving industrial development and growth, and the capacity of the environment to dispose of waste, air pollution, and health threats, which, while maintaining industrial growth and economic development, reduces the growing trend of environmental destruction. Therefore, provincial institutions have moved towards replacing less polluting sources and using new technologies to reduce pollution. Then, in the next stage, increasing industrial activities and production inputs, including energy, have caused pollution and greenhouse gas emissions.

Figure (14) shows the impact of decision-making variables on the energy consumption objective function. As the results show, the greatest impact on the energy consumption objective function was economic growth and industrialization rate.

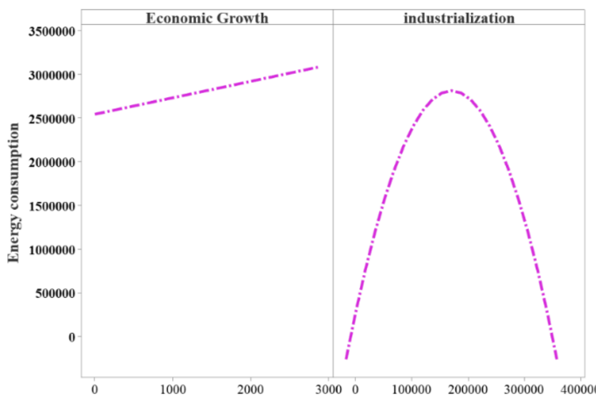


Figure (14). The impact of decision-making variables on energy consumption
Source: *Research calculations*

In summary, there are two major approaches to the impact of fiscal decentralization on energy consumption. These two approaches are: the competition-up approach and the competition-down approach. As expected, economic growth has led to an increase in energy consumption. It seems that in economies that depend on environmentally polluting industries or have low institutional quality and environmental standards are not enforced, restrictions on fossil fuel consumption are reduced in the process of implementing fiscal decentralization to attract investors. In this approach, even governments support heavy industries that consume a lot of energy to achieve the goal of increasing economic growth. Therefore, fiscal decentralization increases energy consumption. The second approach is true. In line with the pattern of industrialization at the beginning of fiscal decentralization, provincial institutions reduce restrictions on energy consumption to compete with institutions in other provinces in attracting investors and increasing their economic growth. In the path of economic growth of their regions, they even support some heavy and energy-intensive industries, which in turn increases energy consumption, but in the later stages, with the increase in environmental pollution as a result of excessive energy consumption, it forces provincial institutions to impose restrictions on energy consumption and control its consumption to deal with this problem. On the other hand, by implementing financial decentralization, more revenues accrue to provincial organizations, and they use these revenues to encourage manufacturers to use low-energy technologies in production, which in turn leads to a reduction in energy consumption.

Figure (15) shows the contour of the impact of decision-making variables on carbon dioxide. As the results show, only the simultaneous change of the two parameters of urbanization and industrialization had the greatest impact on carbon dioxide.

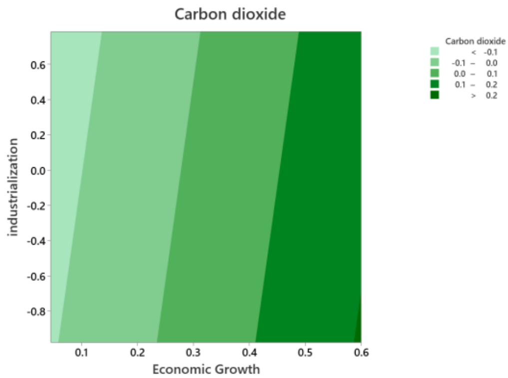


Figure (15). Contour of the impact of decision variables on carbon dioxide
Source: *Research calculations*

Figure (16) shows the contour of the impact of decision-making variables on energy consumption. As the results show, only the simultaneous change of the two parameters of industrialization and economic growth had an impact on energy consumption.

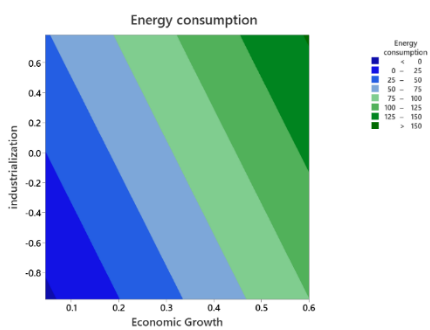


Figure (16). Contour of the impact of decision-making variables on energy consumption
Source: *Research calculations*

5. Concluding Remarks

In this paper, the green paradox in fiscal decentralization was investigated using multi-objective optimization and response surface methodology (RSM) in Iran. Given that in recent years the world has faced threats such as increased energy consumption, destruction, and extreme weather events following the increase in the production and use of fossil fuels, following such changes, one of the methods that has been considered an effective strategy for improving and maintaining environmental health has been the question of what the impact of fiscal decentralization is. For this purpose, multi-objective optimization was performed using the RSM method, and the most optimal values for the objective functions and optimization variables were obtained. For optimization, two scenarios and four policy variables were selected and introduced as optimization variables. Two objective functions of carbon dioxide and energy consumption were also selected for optimization in two scenarios. The most influential design variable is the rate of urbanization, industrialization, and economic growth, and the revenue decentralization variable had the least impact. In addition, the results showed that the urbanization rate and industrialization rate had the greatest impact on reducing the growth of carbon dioxide, while the urbanization rate and industrialization rate had the greatest impact on energy consumption and causing its growth to decrease. In the second scenario, the effect of decision-making variables on the carbon dioxide objective function shows that economic growth and industrialization rate have the greatest impact. Also, economic growth and industrialization rates have had the greatest impact on energy consumption. In both scenarios, revenue decentralization and expenditure decentralization had a negligible and negative effect on energy consumption and carbon dioxide emissions, so it seems that a green paradox has not been created.

1.5. Policy implication

1- Considering the results obtained from the impact of both revenue and expenditure decentralization indicators on pollution emissions and energy consumption, the government can, by implementing decentralization policies, delegate specific and relative powers to the provinces so that they can be decision-makers and implementers in matters related to their localities, independent of the direct intervention of the central government. Of course, in the cost matters of each province, more attention should be paid to the quality of institutions for controlling pollution and energy consumption.

2- Based on the results obtained from the impact of decentralization of revenue and expenditure on pollution emissions and energy consumption, attention should be paid to the regulation and implementation of tax policies in each province, such as determining provincial tax rates, which can be used in economic and environmental policies to control pollution and energy consumption.

3-By establishing environmental non-governmental organizations (environmental organizations) in each province, efforts should be made to reduce each province's revenue and expenditure channels to the lowest possible level for controlling pollution and specific energy consumption and the consequences of environmental hazards in each province.

Author Contributions

Conceptualization, methodology, validation, formal analysis, resources, by all authors.

Funding

This research received no external funding.

Conflicts of Interest

The authors declare no conflict of interest.

Data Availability Statement

The data used in the study were derived from publicly available literature and governmental documents.

Acknowledgements

Not applicable

References

Ahmed, Z., Asghar, M. M., Malik, M. N., & Nawaz, K. (2020). Moving Towards a Sustainable Environment: The Dynamic Linkage between Natural Resources, Human Capital, Urbanization, Economic Growth, and Ecological Footprint in China. Resour. Policy 67, 101677. doi:10.1016/j.resourpol.2020.101677.

Anvari, E; Jafari, E; Farazmand, H; & Montazer Hojat, A. H. (2024). Prediction of Fiscal Decentralization Considering Energy Consumption and Environmental Impacts by using Hybrid Intelligent Models with Optimization Algorithms. Stable Economy,5 (1), 62-28.

Buser, W., (2011). The impact of fiscal decentralization on economics performance in high-income OECD nations: an institutional approach, Public Choice. 149, 31.

Chen, X., Chang, C. (2020). Fiscal Decentralization, Environmental Regulation, and Pollution: A Spatial Investigation. Environ. Sci. Pollut. Res. 27(25), 31946–31968. doi:10.1007/s11356-020-09522-5.

Cheng, Y., Awan, U., Ahmad, S., & Tan, Z. (2021). How Do Technological Innovation and Fiscal Decentralization Affect the Environment? A Story of the Fourth Industrial Revolution and Sustainable Growth. Technol. Forecast. Soc. Change, 162, 120398.

Comola, M., de Mello, L. (2010). Educational Attainment and Selection into the Labour Market: The Determinants of Employment and Earnings in

Indonesia'. Working Paper 2010-06. Paris: Paris School of Economics, forthcoming.

Elheddad, M., Djellouli, N., Tiwari, A. K., & Hammoudeh, S. (2020). The Relationship between Energy Consumption and Fiscal Decentralization and the Importance of Urbanization: Evidence from Chinese Provinces. Journal of Environmental Management, 264, 110474.

Gao, Y., Li, Z., & Wang, Z. (2025). Fiscal Decentralization, Green Innovation and low-carbon Transition of Heavily Polluting Firms. J. Environ. Manag. 380, 124897. doi:10. 1016/j.jenvman.2025.124897

Gerlagh, R., Liski. M. (2011). "Strategic Resource Dependence." Journal of Economic Theory 146(2): 699–727.

Hao, Y., Chen, Y. F., Liao, H., & Wei, Y. M. (2020a). China's Fiscal Decentralization and Environmental Quality: theory and an Empirical Study. Environ Dev Econ;25(2): 159e81.

He, Q. (2015). Fiscal Decentralization and Environmental Pollution: Evidence from Chinese Panel Data. China Economic Review,36:68-100

Jafari Samimi, A., Karimi Petanlar, S., Keshavarz Haddad, G., & Alizadeh, M. (2010). Fiscal Decentralization and Economic Growth: A Nonlinear Model for Provinces of Iran. Iranian Economic Review, 15(26), 125-133.

Jabbari, L; and Salem, A. A. (2021). Investigating the Nonlinear Effect of Fiscal Decentralization on Energy Consumption in Iranian Provinces Using the Quantile Panel Model. Iranian Journal of Energy Economics. 9 (36).,

Ji, X., Umar, M., Ali, S., Ali, W., Tang, K., and Khan, Z. (2020). Does Fiscal Decentralization and Eco Innovation Promote a Sustainable Environment? A Case Study of Selected Fiscally Decentralized Countries. Sustainable Development.

Khanzadi, A; Heydarian, M; & Moradi, S. (2019). Analysis of the Effects of Fiscal Decentralization and its Environmental Consequences in the Provinces of Iran. Quarterly Journal of Economic Modeling. 12(41), 133 – 159..

Kleijnen, Jack PC. (2015). Response surface methodology. Handbook of simulation optimization. Springer, New York, NY, 81-104.

Kuai, P., Yang, S., Tao, A., Zhang, S., & Khan ZD. (2019). Environmental Effects of Chinese Tyle Fiscal Decentralization and the Sustainability Implication JCleanProd;239:118089. https://doi.org/10.1016/j.jclepro.2019.118089.

Liu, L., Ding, D., & He, J. (2019). Fiscal Decentralization, Economic Growth, and Haze Pollution Decoupling Effects: a Simple Model and Evidence from China Computational Economics, 54(4), 1423–1441https://doi.org/10.1007/s10614-017-9700-x

Malik, S., Hasan, M., & Hussain, S. (2006). Fiscal Decentralization and Economic Growth in Pakistan. The Pakistan Development Review, Vol. 4(45), pp. 845 – 854.

Martinez-Vazquez, J., Mcnab R. M. (2003). Fiscal Decentralization and Economic Growth, World Development, 31, 1597–1616.

Matheus, K., José Alberto, F., & António Cardoso, M. (2019). The Effect of Fiscal and Financial Incentive Policies for Renewable Energy on CO2 Emissions: The Case for the Latin American Region. Ext. Energy-Growth Nexus-Theory Empir. Appl. 5,1 41–172. doi:10.1016/B978-0-12-815719-0.00005-X.

Morgan, K. (2002). English Question: Regional Perspectives on a Fractured Nation Regional Studies, Vol. 36 No. 7, pp. 797-810, doi: 10.1080/0034340022000006114.

Musgrave, R. A. (1959). The Theory of Public Finance, McGraw Hill, New York.

Oates, E. (1972). Fiscal Federalism, Harcourt Brace Jonanovich, New York.

OECD. (2019). Understanding Decentralisation Systems, in Making Decentralisation Work: A Handbook for Policy-Makers. OECD Multi-level Governance Studies, OECD Publishing, Paris, pp.25-58.

Pansuwan, A. (2009) Regional Specialization and Industrial Concentration in Thailand 1996-2005, Indonesian Journal of Geography, 41 (1): 1-17.

Pindyck, R. (1973). Optimal Planning for Economic Stabilization. North – Holland, Amsteydam.

Romero Molina, A. (2018) Environmental Pollution and Fiscal Decentralization. On the Role of Institutions.

Satrovic, E., Somoye, A., Olaleye, B. R., & Lekunze, J. N. (2025). Reconciling fiscal decentralization, environmental protection expenditures, and stringent regulations with the ecological priorities of the European Union. Frontiers in Environmental Science, 13, 1600303.

Soori, A. (2006). Mathematical Economics: Methods and Applications. Organization for Study and Compilation of Humanities Books, University of Humanities Research and Development Center.

Song, Y., Ma, J., Guan, S., & Liu, Y. (2023). Fiscal Decentralization, Regional Innovation, and Industrial Structure Distortions in China. Sustainability, 15(1): 710.

Su, C. W., Umar, M., & Khan, Z. (2021). Does Fiscal Decentralization and Eco-Innovation Promote Renewable Energy Consumption? Analyzing the Role of Political Risk. Science of The Total Environment, 751, 142220.

Tiebout, C.M. (1956). A Pure Theory of Local Expenditures. J. Polit. Econ. 64, 416–424.

Udeagha, M. C., Breitenbach, M. C. (2023). Revisiting the nexus between Fiscal Decentralization and CO2 Emissions in South Africa: Fresh Policy insights. Financial Innovation, 9(1), 1-46.

Van Der Ploeg, F., Withagen, C. (2012). Is there a Green Paradox? J. Environ. Econ. Manage. 64 (3), 342–363.

Wang, L., Gao, Y. (2018). Fiscal Decentralization and Upgrading of Industrial Structure: Empirical Evidence from a Quasi-Natural Experiment of Province-Managing-County Reform. Financ. Trade Econ. 39, 145–159.

Wang, L., Chang, H.-L., Rizvi, S.K.A., & Sari, A. (2020). Are Eco-Innovation and Export Divers Fiction Mutually Exclusive to Control Carbon Emissions in G-7 countries? J. Environ.

Wang, K.L., Zhao, B., Ding, L.L., & Miao, Z. (2021). Government Intervention, Market Development, and Pollution Emission Efficiency: Evidence from China. Sci Total Environ. 757:143738. https://doi.org/10.1016/j.scitotenv.2020.143738.

Wu, A. M., Ye, L., & Li, H. (2019). The impact of Fiscal Decentralization on Urban Agglomeration: Evidence from China. Journal of Urban Affairs, 41(2), 170-188.

Xu, M. (2022) Research on the Relationship between Fiscal Decentralization and Environmental Management Efficiencies under Competitive Pressure: Evidence from China. Environ Sci Pollut Res 29(16):23392–234.

Yang, Y., Tang, D., & Zhang, P. (2020). Effects of Fiscal Decentralization on Carbon Emissions in China. Int. J. Energy Sect. Manag. 14 (1), 213–228. doi:10.1108/ijesm-03-2019-0001.

Yıldız, T. D. (2025). Will the resource potential of critical raw materials used in electric cars in Turkey be sufficient for the domestic automobile factory?– a review. Mineral. Resour. Manag., 29. doi:10.24425/gsm.2025.153167

Zhang, G., Liu, W., & Duan, H.(2020). Environmental Regulation Policies, Local Government Enforcing and Policy-Intensive Industry Transfer in China. Comput. Ind. Eng. 148, 106748

Zhang, K., Zhang, Z.Y., & Liang, Q.M. (2017). An Empirical Analysis of the Green Paradox in China: From the perspective of fish decentralization. Energy Policy. 103, 203–211.