Operations Management Research (2024) 17:660–682
https://doi.org/10.1007/s12063-024-00441-z

Governance intervention policies in the production competition of biofuels and fossil fuels: a pathway to sustainable development

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Received: 21 February 2023 / Revised: 4 December 2023 / Accepted: 20 January 2024 / Published online: 2 March 2024

Abstract

Environmental pollution and social welfare have become significant issues for governments and policy-makers in both developed and developing countries. That's why there is an essential need to develop a comprehensive model for investigating the impact of government interventions on the production quantities of refineries considering competition between bio and oil fuels. Although some papers have focused on the tariff policy as a subsidy or a tax scheme, there is still a lack of models taking the government's role as an independent player in the competitive market of refineries into account. Also, previous studies have not modeled the government and refineries competition as a competitive game in which they are the leader and follower, respectively. Moreover, no study has discussed the issue based on the sustainability goals of the government in the contexts of economic, environmental, and social aspects considering the selection of the tariff or investment strategy. To fill these gaps, this paper develops a bi-level multi-objective mathematical model incorporating two policies of tariff and investment on production capacity as environmental governance policy in refineries competition. The first level presents government problems under sustainability considerations. In the second level, the competition of bio and oil refineries is formulated using the Cournot competition game model. The transformation method is proposed by applying KKT conditions to obtain the best responses of refineries in the corresponding game. In addition, the revised multi-choice goal programming approach is used to solve proposed multi-objective model. A case study is presented to show the applicability of the model and the sensitivity analysis of the critical parameters is conducted. The findings show that government intervention policies on fuel production and consumption can be positively and directly related to reducing pollution and increasing social welfare.

Keywords Cournot game · Refineries' competition · Government interventions · Multilevel programming · Sustainable development · Revised multi-choice goal programming

1 Introduction

Instability from oil shocks in the Middle East, uncertainty about nuclear safety, and environmental factors caused by nonrenewable sources of energy are some of the concerns about local and international energy systems (Annual Energy Outlook 2019). Moreover, climate changes, the impacts of air pollution, worldwide warming, and environmental concerns have enforced governments and companies to monitor and pursue sustainability issues in the different industrial sectors (Szargut and Stanek 2008; Yu-zhuo et al. 2017). The Kyoto Protocol is an international treaty that extends the 1992 United Nations Framework Convention on Climate Change, which recommends parties to decrease emissions caused by greenhouse gases (GHGs) based on the scientific consensus that global warming caused by human-made CO_2 emissions (Huang et al. 2008; Jafari-Raddani

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et al. 2023). The Kyoto Protocol is based on the concept of common but differentiated responsibilities: it recognizes the fact that individual nations have a distinct capacity to control climate change based on their economic development. Therefore, it directs countries to decrease the prevailing emissions because they are responsible for the current situation of greenhouse gasses in the atmosphere. According to this guideline, the states attempt to reduce pollutants that affect the climate.

High energy consumption in all industries, especially in transportation, manufacturing, and industries, has been caused by the rise in population (Liao and Cao 2018). Energy plays a vital role in sustainability aspects, including socio-economic and environmental aspects (Smith 2010). The most emissions that contain different pollutants are produced by fuel consumption (Wang et al. 2019). The limitations of nonrenewable energy and the pollution caused by fossil fuels have made it difficult to achieve sustainability. According to the definition of sustainability, the requirements of the present should be fulfilled without endangering future generations (Report WCoEaD 1987). Therefore, effective management of energy resources is required, which can reduce the consumption of resources and create a healthy and clean environment (Markovska et al. 2016).

Currently, the energy demand of the world continues to rise at an estimated annual rate of 1.8%, as nations evolve especially, whereas, at the same time, the energy supply appears to be confined (Farmer and Doherty 2019). The reason for this is that 75–85% of the world's energy is supplied by fossil fuels, and their supply is limited (Farmer and Doherty 2019; Martikainen 2019; Narayan Rath et al. 2019). Moreover, the burning of fossil fuels has increased the atmospheric concentration of some GHGs that are considered responsible for global warming (Zokaee et al. 2021). The other impacts of the burning of fossil fuels include the production of acid rain, smog, and an increase in the atmospheric particles. Also, the world's population is predicted to grow at about 1% per year, which indicates that the worldwide demand for energy will continue to increase. Furthermore, fossil fuels are expected to continue to dominate the energy industry for some time, and petroleum will be used as the most strongly traded fuel (Monasterolo and Raberto 2019; Braungardt et al. 2019; Dumka et al. 2019; Hunt and Weber 2019).

Therefore, alternative renewable energy resources with sustainable supplies are required due to limited fossil fuels. A steady amount of energy can be provided by renewable sources of energy (Kristianto and Zhu 2019; Rowe et al. 2009; Quadrelli and Peterson 2007). The fact that fossil fuels can be effectively replaced by a single renewable energy source does not make sense. If renewable sources are combined, they may replace fossil fuels. Probably, this would require being in conjunction with a reduction in energy use and an increase in efficiency. Therefore, the challenge for all governments is to move toward a safer low-carbon energy consumption state without impeding their economic and social development (Maeda et al. 1995; Kenisarin and Mahkamov 2007; Gronkvist et al. 2006).

A biofuel is a fuel that is produced by biomass using modern methods rather than a fuel produced by the very quiet geological procedures used in fossil fuel formation, such as oil. However, the term biomass only indicates the biological raw material from which the fuel is produced or a type of the end product that is chemically modified. If biomass used in production, biofuel can rapidly regrow, and the fuel is generally considered as a form of renewable energy (Shabani and Sowlati 2013; Cucchiella et al. 2019). Biofuel can be produced by plants or from agricultural or industrial waste (if the waste is of biological origin). Generally, renewable biofuels require modern carbon fixation, such as in plants or microalgae, by the photosynthesis method. In order to decrease dependence on petroleum, the International Energy Agency (IEA) recommends biofuels to satisfy more than a quarter of the world's demand for transportation fuels by 2050 (Shabani et al. 2014).

Using fossil fuels to generate energy has increased both the concentrations of CO_2 in the atmosphere and the related climate change and dependency on global oil markets that are politically vulnerable. These implications have accelerated both substantial types of research on alternative energy sources and energetic policy discussions on strategies to promote them (Perrin et al. 2008). Therefore, governments motivate refineries by providing incentive schemes to produce energy that makes the air less pollutant (Blumstein 2010; Vine 2008). In the recent years, the implementation of some financial policies, such as energy tax or subsidy schemes, has improved energy consumption and encouraged energy-intensive industries to use these schemes (Mizobuchi and Takeuchi 2016; Tao and Yu 2011; Torabzadeh et al. 2022). The governments design some policies that include oil and bio-refineries, which can be very effective in this sector. Thus, in this paper, two types of policy on tariff and capacity of the bio-refineries are considered. In our model, government tariff rate (as tax or subsidy) per unit of production in bio and oil refineries are considered as free decision variables in profit functions of refineries. Tariff policy can be implemented as the first and second scenarios for both bio and oil refineries. Tariff policy is defined as tax and subsidy, which is related to the kind of fuel that is produced. The objective of the government is to achieve the highest social welfare with the lowest impact on the environment. According to the type of fuel that is provided, the government may offer subsidy or receive taxes. If optimal values for tariff rates are positive, it means that the government offers a subsidy to refineries. On the contrary, a negative tariff would act as a tax that reduces the profit of refineries. In this paper, we attempt to model these kinds of government policies to achieve sustainability goals such as economic, social, and environmental aspects. Also, we tried to show government support in motivating companies to achieve sustainable objectives.

Also, in this article, the impact of government interventions on the production quantities of refineries under a competitive situation is investigated. First, a bi-level model is developed using multi-objective mixed-integer nonlinear programming (MINLP). The first level presents government problems under sustainability considerations, including economic, environmental, and social aspects. In the second level, the competition of bio and oil refineries is formulated by using the Cournot competition game model. Second, two policies of tariff and co-investment on production capacity are incorporated as environmental governance policy in refineries competition. As the solution approach, the transformation method is proposed by applying KKT conditions to obtain the best responses of refineries in the corresponding game. Next, the revised multi-choice goal programming approach is used to solve the resultant multi-objective MINLP model. The main contribution of this research is to investigate the impact of government and policy-maker's interventions on the production quantities of bio and oil refineries under competitive situations for achieving sustainability aspects including economic, environmental, and social welfare. Therefore, according to these policies, governments of developed and developing countries can achieve their sustainability goals. Moreover, no study has discussed the issue based on the sustainability goals of the government in the contexts of economic, environmental, and social aspects considering the selection of the tariff or investment strategy.

In particular, the objective of this paper is in answering the following questions:

1. How can the government reach its sustainability goals?
2. What is the best policy to help achieve government sustainability objectives?
3. What is the best tariff policy (tax or subsidy) that government can choose as a leader under competition of bio and oil refineries?
4. What are the advantages of such policies under competition between bio and oil refineries for the policy maker's as a leader?

The rest of the study is structured as follows: the literature review involves a brief literature of the game theory approaches in bio and fossil fuels, and government intervention and regulation have been presented in Section 2. The methodology framework is presented in Section 3. The assumptions, model formulation, mathematical model of refineries, government policies, and mathematical model of the government are presented in the problem definition and mathematical notations as Section 4. Section 5, as solution approach included transformation approach and revised multi-choice goal programming. A numerical example and case study are discussed in Section 6. Section 7 is related to discussions and managerial insights. The conclusions and possible ideas for further studies are presented in Section 8.

2 Literature review

This paper considers the competition between bio and oil refineries under government interventions. The government, as a leader, plays an essential role in the competitive environment in the energy sector. Therefore, defining the amount of production in a competitive situation will increase the profit of the players. In this section, we review the literature related to the case under study.

2.1 The game theory approaches in bio and fossil fuels

The supply chain (SC) of biofuels comprises various equipment and departments that are responsible for biomass manufacturing, conversion of biomass to biofuels, and delivery systems of biofuels. A biofuel SC design induces a significant impact on the predominance of biofuels over fossil fuels. An efficient optimization strategy is required to ensure the financial, environmental, and social viability of the SC, taking into account the payoffs of each SC member (Mafakheri and Nasiri 2014). Therefore, adopting game theory appears to be a logical solution in order to assist decision making in the SC in the case of conflict and collaboration between parties (Zhai et al. 2016; Cao et al. 2016). By using a nonzero-sum game, Florentino and Sartori (2003) proposed a mathematical model with two competing goals in a SC for biofuel. In order to model relationships between the participants in the biomass SC, Nasiri and Zaccour (2009), Chen and Zhi-Hua (2018), and Sun et al. (2011) applied the game theory.

The competition among bio-refineries in SCs for biofuels discussed by Yue and You (2014). The anticipated increase in the consumption of biofuels induces further demand for various feedstocks of biomasses. Generally, biofuels are generated from different sources, such as food plants, including maize, labyrinth, etc., that are referred to as feedstock for the first generation of biomasses. Therefore, one of the most significant limitations to biofuel production is the food crisis, directly due to products intended for energy rather than food. A game model was presented by Luo and Miller (2013) for analyzing choices in the manufacturing of biomass and bioethanol. They estimated the incentives required to drive the sector to use nonfood sources, such as switchgrass, also known as biomass feedstock of the second generation. On the other hand, another issue is that the land required to produce food would be diverted to second-generation biomass manufacturing. By proposing a cooperative bi-level Stackelberg game model, Bai et al. (2012) analyzed game-theoretical models that integrate the land use by the farmers and market choices into the SC issue of biofuel producers. A non-cooperative bi-level Stackelberg leader–follower game model and a cooperative game model were created in order to manage the possible company partnership situations between feedstock providers and biofuel manufacturers. The impact of public interference on land use in a competitive SC of biofuels was explored to balance food and energy production (Bai et al. 2016).

Considering the government and private sectors, Moradi Nasab et al. (2016) provided an integrated economic model of fossil fuel energy planning. They discussed the competition between refineries at the refinery level and between distribution centers within the distribution center level. In another study, Moradi Nasab et al. (2018) developed a two-level model for a sustainable petroleum SC, and there was a competition between the SCs of the government and private sectors.

Using a partial equilibrium model under land availability limitations, Benjamin and Houee-Bigot (2007) focused on world arable crop markets and simulated the effect of alternative domestic and global agricultural policies. A firm-level assessment for an ethanol refinery and compared prices of maize and ethanol under zero profit performed by Tyner and Taheripour (2008).

In order to model the relationships in food and fuel economies between supply and demand, Rajagopal et al. (2009) formulated a partial multimarket equilibrium structure. On the contrary, general equilibrium models consider worldwide financial consequences rather than regional, industrial, or commodity-level consequences. In order to model and analyze the SC for biomass power, Zhai et al. (2016) used a game-theoretical approach. The issue of policy selection, by the government, is discussed on the basis of vertical relationships between three players: farmers, biomass power plants, and government.

In order to find the portfolio of energy transportation equilibrium under the environmental protection policy, Hua and Chen (2019) reported a mathematical program with a model of limitations of equilibrium. The model uses the optimum circumstances of Karush–Kuhn–Tucker to portray the profit maximization of fuel suppliers. In both the market for goods and carbon trading, profit was calculated. Chen et al. (2010) investigated the tradeoff between food and biofuel by comparing losses and gains in consumer surplus in different socioeconomic industries.

In a closed-loop supply chain of supplier and third-party dual collection channels, Wan and Hong (2019) developed Stackelberg game models to explore the best pricing and recycling policies. In their supply chain the transfer rates charged by the vendor to the two recyclers are either uniform or different, and government subsidies are given to either the manufacturer or the two recyclers. The impact of rivalry on strategic output planning at a refinery investigated by Tominac and Mahalec (2017). They looked at many rival refineries that are trying to take control of the supply of petroleum products for sale in domestic and global markets. For each refinery, decision variables such as crude oil purchasing amounts, mix volumes, and commodity volumes are taken into account.

The feasibility of investment in refinery construction is discussed in their research. This paper reveals major investment issues with consequences for the future of the petroleum industry by using a game theory approach. Their research is based on the three-phase Stackelberg game theory. Their research shows how policymakers can convince investors that their investments will be profitable by assessing the number of subsidies and intermediate producers' production (Babaei et al. 2020).

A supply chain would include a refinery and a retailer proposed by Zhang and Yousaf (2020). In their study, the refinery invested in renewable technology to minimize greenhouse emissions, and the government is contemplating retail tax and subsidy policies. The volume of subsidy or tax, the wholesale price, and the final price of the product are the decision variables for the government, refinery, and retail. Their problem is modeled using a game-theoretic approach and approached in two scenarios: centralized and decentralized. Also, a supply chain that included crude oil suppliers and refineries considered by Nicoletti and You (2020). They proposed that the refinery seeks economic and environmental objectives while producers aim to increase profits. The modeling took into account pricing, environmental effects, transportation distance, and structure, and the problem was studied using Stackelberg game theory and bi-level programming.

The extent of fuel efficiency development and the output of conventional internal combustion engine vehicles and new technology vehicles was addressed using a game-theoretic approach. Contracts for research and development cost-sharing and arrangements for internal combustion engine vehicle sales sharing are intended to coordinate traditional automobile supply chains (Ma et al. 2021). The characteristics of the investigated articles on using the game theory approach on fuels are summarized in Table 1.

2.2 Government intervention and regulation

The environmental and social problems enforce countries to define incentive schemes for encouraging refineries and consumers in order to produce and use fuel with low pollutants. Therefore, biofuel can be considered a good alternative. In this case, the government plays a significant role in defining the price of fuel by offering a tariff for refineries and

Table 1 Characteristics of the published papers on the game theory approaches in bio and fossil fuels

Reference	Game Structure	Bi-level	Methodology Approach	Government Policy			Decision Variable
				Tax	Subsidy	Investment	
Bai et al. (2012)	Stackelberg	✓	mixed integer quadratic programming	×	×	×	refinery location variables, market equilibrium prices, amount of corn supplied
Yue and You (2014)	Stackelberg	✓	mixed-integer nonlinear programming, non-cooperative	×	×	×	facility location, technology selection, material input/output and price
Bai et al. (2016)	Stackelberg	×	mixed integer, Game theory	×	×	×	refinery location, procurement price, market price
Zhai et al. (2016)	Nash	×	Game theory	×	✓	×	Purchasing price, Sale quantity, subsidized price
Cao et al. (2016)	Stackelberg	×	cooperate and coordinate	×	×	×	order quantity, sales price, carbon emission quota, wholesale price
Moradi Nasab et al. (2016)	Nash and Stackelberg	×	integrated economic model	×	✓	×	unsubsidized and subsidized price, demand, production rate
Moradi Nasab et al. (2018)	Nash and Stackelberg	✓	mixed-integer linear programming	×	✓	×	unsubsidized and subsidized price, demand, production rate, number of labors
Nicoletti and You (2020)	Stackelberg	✓	Game Theory, Bi-level programming	×	×	✓	selling price, amounts of each oil, total kg CO$_2$-eq produced, energy content of one barrel of each oil
Zhang and Yousaf (2020)	Stackelberg	×	Game Theory	✓	✓	×	The volume of subsidy or tax, the wholesale price, and the final price of the product
In our research	Cournot	✓	multi-objective mixed-integer nonlinear programming	✓	✓	✓	type of government strategy, production, pricing, capacity, investment, tariff rates

devising the market price of the bio and oil fuels. Therefore, this phenomenon is called the competition between bio and oil fuels in the market.

In the rest of the literature reviews, the papers that provide competition and government issues are considered. The fewer papers discussed the competition between refinery and fuel sectors, most of the research studies are conducted in the field of the energy sector and government interventions.

The competition between thermal and renewable power plants is formulated by Ghaffari et al. (2016). In their models, the prices of tradable green certificates are determined by the government, which is fixed. Analyzation of the increasing use of photovoltaic solar systems for households done by Macintosh and Wilkinson (2011) by considering the Australian government rebate scheme. In Japan, Zhang et al. (2011) proposed regional diffusion strategies in order to spread environmental awareness among citizens and to manage the adverse impact of installation expenses for supporting the photovoltaic system. Sheu (2011) also considered competitive green supply chains (GSCs) and observed that benefits, social welfare, and bargaining power of chain members are influenced by manufacturers, reverse logistics providers, and public intervention. The competition within GSCs analyzed by Sheu and Chen (2012). They examined the impact of government subsidies and taxation on the performance of GSCs. They demonstrated that government subsidies and taxation policies promote the use or production of green products supplied by providers and producers. Also, the renewable energy and climate policies positively influenced photovoltaic electricity generation investigated in Sivaraman and More’s (2012) study.

The renewable energy sources that reduce hazardous emissions were reviewed by Iqbal et al. (2014). In their study, the characteristics of users who apply solar cells in powerhouses, homes, and industrial plants, were also discussed. The government tariffs that affect the profit and competition between green and typical SCs analyzed by Hafezalkotob (2015). Rezaee (2016) compared solar photovoltaics (PVs) with fossil fuels and reported the advantages of solar photovoltaics in construction.

The models of cooperation and competition between two GSCs analyzed by Hafezalkotob (2017). In their study, the state plays an essential role in managing the skills of SCs supported by tariffs. Therefore, public interference can influence both cooperation and competition of GSCs. The models of mathematical programming about the energy-saving, social welfare, and revenue-seeking policies of governments are formulated. In this research, the government should orchestrate GSCs through an effective tariff mechanism to fulfill the economic, social, and environmental goals.

A new sustainable SC consisting of an energy-efficient manufacturer, an inefficient manufacturer, and an energy supplier involved in energy efficiency programs is investigated by Safarzadeh and Rasti-Barzoki (2019). They proposed a multistage game model for designing an efficient program considering two scenarios: tax deduction and subsidy scheme. Under three government policies and two SC decision systems, Giri et al. (2018) formulate a non-linear, bi-level interactive model between the government and SC members. In order to examine the effects of government financial interventions on GSCs, Hafezalkotob and Zamani (2019) proposed a game-theoretic model. Moreover, they formulated a bilevel model with different environmental pollution levels for products in GSCs.

A Stackelberg game between the government and a multistage GSC is investigated by Halat and Hafezalkotob (2019). Governments and policy-makers are making every effort to mitigate pollution and climate change. Therefore, they set different rules to reduce greenhouse gases and carbon footprints to achieve a high level of social welfare.

The producer-retailer environment in which the supplier has the options to produce a product to emit less carbon during manufacturing and use less energy when the product is purchased by consumers in order to investigate how carbon taxes and energy-saving incentives impact operating decisions of businesses examined by Yuyin and Jinxi (2018a). Also, in other study, Yuyin and Jinxi (2018b) developed a Stackelberg game model to research the collaboration of upstream and downstream businesses of a SC in energy saving and pollution reduction. The supplier first works to agree on a cost-sharing deal; then the producer successively determines the level of energy-saving, the level of carbon emissions, and the wholesale price.

The role of the government in the power plant rivalry on an electricity market, with considering the government's Stackelberg leadership, is being investigated by Hafezalkotob and Mahmoudi (2017). A one-population evolutionary power plant game model is being developed to research how its development strategy relies on government-imposed tariffs.

The Malaysian government has been focused on investments in the petroleum sector since 2011. Strategies such as risk service contract, deduction of income tax, waiver of the obligation of selling oil have been used to guarantee the income of the investor (Kraal 2019). The importance of investment policy in petroleum refineries in improving production and reducing shortages of petroleum products in the petroleum supply chain investigated by Itsekor (2020). Their study was founded on the resource-based view concept.

A dual-channel green supply chain management problem under an eco-label policy presented by Gao et al. (2021). The government establishes a green standard for manufacturers. The manufacturer can only receive an eco-label and government subsidies if the product meets the standard. They recommend a two-part tariff contract for supply chain members. The agreement encourages supply chain participants to make appropriate decisions to increase profits while still greening the supply chain. The current study also shows the effect of the eco-label strategy on the supply chain's economic and environmental efficiency.

In a two-echelon dual-channel supply chain, Zhenkai et al. (2020) focused on government green incentives. In their study, optimal choices made by a manufacturer and dual-channel retailers. A decentralized supply chain, as well as a centralized supply chain, are all considered. Sufficient and appropriate requirements are proposed to ensure that the two supply chains frequently operate when receiving government subsidies.

In order to maximize the environmental and financial benefits of a consolidated scenario, Wang et al. (2020) took into account how the government's environmental tax policies on consumers can affect supply chain corporations' decision-making. They propose an improved side-payment self-enforcing contract. Furthermore, it serves as a model for the government to follow to implement both the carbon cap policy and the environmental tax policy.

To support long-term green production with the consideration of government financial intervention, we develop a three-population model of suppliers, manufacturers, and governments based on evolutionary game theory and investigate the evolutionary stable strategies of their unilateral and joint attitudes. Moreover, system dynamics is used in scientific research to investigate the complex relationship of populations' strategies, and the main factors

Table 2 Characteristics of the published papers on government intervention

Reference	sector		Government Policy			Approach		
	energy	fuel	Social Welfare	Economical	Environmental	Case Study	Statistical Analysis	Game Theory
Sheu and Chen (2012)	✓	×	×	✓	×	×	✓	✓
Sivaraman and More (2012)	✓	×	×	×	✓	×	✓	✓
Hafezalkotob (2015)	×	×	×	✓	✓	×	✓	✓
Ghaffari et al. (2016)	✓	×	×	×	×	×	✓	✓
Hafezalkotob (2017)	✓	×	✓	✓	✓	×	✓	✓
Yuyin and Jinxi (2018a, b)	✓	×	×	✓	✓	×	✓	✓
Safarzadeh and Rasti-Barzoki (2019)	✓	×	×	✓	×	×	✓	✓
Halat and Hafezalkotob (2019)	×	×	✓	✓	×	×	✓	✓
Zhenkai et al. (2020)	×	×	×	✓	✓	×	✓	✓
Wang et al. (2020)	×	×	×	×	✓	×	✓	✓
Gao et al. (2021)	×	×	×	✓	✓	✓	✓	✓
In our research	✓	✓	✓	✓	✓	✓	✓	✓

influencing stable evolutionary policies are analyzed in detail (Xu et al. 2020). Most related studies provided in Table 2.

2.3 Research gap and contributions

In this paper, it is demonstrated that there are a few studies that considered the competition between bio and oil fuels considering government policies. The majority of the studies have focused on the tariff policy as a subsidy or a tax scheme. Moreover, the government's role as an independent player (policy-maker) in the competitive market of refineries has not been investigated. In our research, the tariff policy and investment policy for increasing the capacity of the refineries are considered.

The main contributions of this study are summarized in the following. (i) The government is considered as a leader of the competitive game, which influences the price of fuels and the profit of bio and oil refineries. (ii) The competition between refineries as a competitive game is considered in this study. (iii) The government attempts to achieving sustainability goals in the contexts of economic, environmental, and social aspects are investigated. (iv) The selection of the tariff or investment strategy is considered in the model.

3 Methodology framework

In the first step, after studying various researches and obtaining a research gap, the primary problem definition is presented. The mathematical modeling of bio and oil refineries under government leadership as a bi-level model for achieving sustainability goals is represented in the second step. In the third step, the objective is to convert the bi-level model to a single-level one by applying the optimality conditions. Next, we will attempt to solve the multi-objective single-level model with the technique of revised multi-choice goal programming. Ultimately, the performance of the model will be illustrated by a numerical example and sensitivity analysis, which will lead to significant managerial results. Figure 1 explains the flowchart of the proposed methodology.

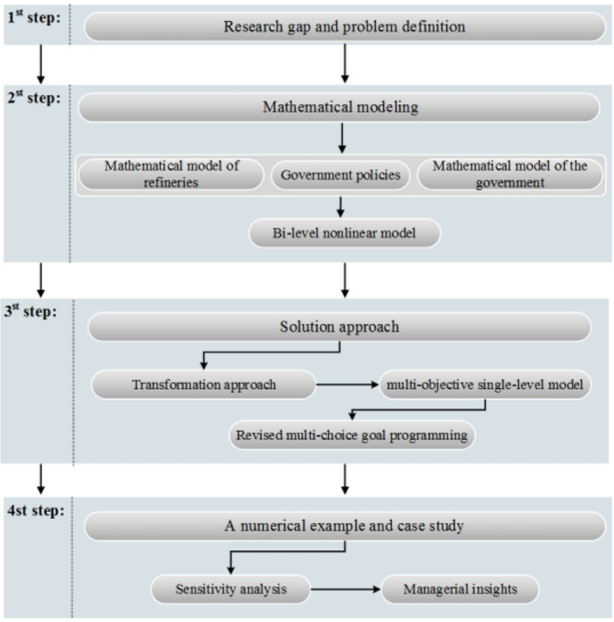

Fig. 1 Flowchart of the proposed methodology

4 Problem definition and mathematical notations

In this paper, a bi-level problem is formulated as mixed-integer nonlinear programming in which the government is placed as a leader at the first level. At the second level, bio-refineries and oil refineries, which provide biofuels and oil fuels, are placed as the followers. The capacity and quality of the fuel that is produced by bio-refineries are different. The quality of produced fuel indicates the number of pollutants originated by burning, such as the amount of sulfur or carbon dioxide, which are produced by burning any biofuels. At the second level, we model competition between biofuel producers, and a set of oil fuel producers to maximize their profits considering the optimum amount of their production following government policies. Moreover, the government, as a leader, defines its policies to achieve sustainability objectives such as economic, social, and environmental aspects. The policies of the government to achieve its sustainability objectives, including subsidies or taxes and investing in refineries to improve their production capacity. Finally, it can be concluded that the aim of the government is to generate revenue, reduce pollution, and achieve high levels of social welfare. Figure 2 illustrates the schematic diagram for the problem definition.

4.1 Assumptions

1. A group of oil fuel producers is considered as a follower in the competitive game. All bio-refineries and the group of oil fuel producers participate in this competitive game, which their competition is through noncooperation.
2. The total production of bio-refineries and oil refineries is considered to be equal to the demand of the entire community. The activity of refineries and the consumption of each fuel (biofuels and oil fuels) generate pollution.
3. The government devises two policies in its incentive plan, and it is assumed that strategies cannot be applied simultaneously: setting tariffs and investing in refineries to increase their production capacity (Safarzadeh and Rasti-Barzoki 2019; Yuyin and Jinxi 2018a, b; Hafezalkotob and Mahmoudi 2017).
4. Price is considered as a function of the production, which depends on its product and other products of fuels available in the market, which is expressed as a linear function (Bárcena-Ruiz and Espinosa 1999; Goering 2007; Xia et al. 2013). The functions related to the price function of biofuels and oil fuels are discussed as follows:

$$p_{bi}\left(Q_b, q_f\right) = \alpha_{bi} - \beta_{bi}q_{bi} - \textstyle\sum_{i'} \beta_{bi\acute{i}}q_{bi'} + \gamma_{bi}q_f \ \forall i \in I \tag{1}$$

$$Q_b = (q_{b1}, q_{b2}, \dots, q_{bn}) \tag{2}$$

$$p_f\left(Q_b, q_f\right) = \alpha_f + \sum_i \beta_{fi}q_{bi} - \gamma_f q_f \tag{3}$$

4.2 Model formulation

In this section, different mathematical models are formulated for bio and oil refineries considering various policies of the government. Then, the government model is presented as a multi-objective form considering the

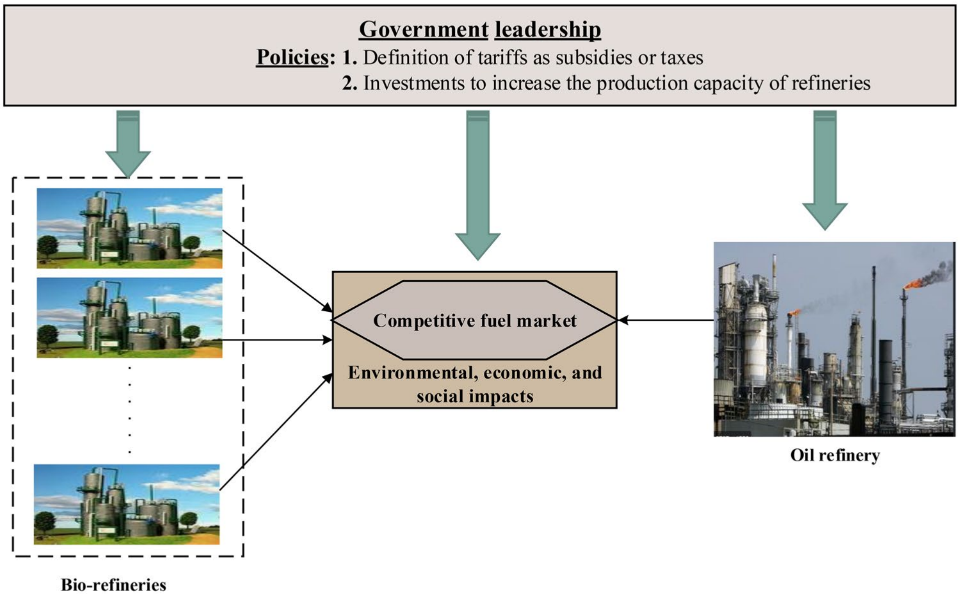

Fig. 2 Schematic design of problem definition

features of sustainability. Finally, the bi-level nonlinear model is presented considering the non-cooperative competition between refineries. Before describing the mathematical model, a list of mathematical notations such as input parameters, and decision variables is presented in Table 3.

4.3 Mathematical model of refineries

The mathematical models of refineries are as follows:

Bio-refineries:

$$\max_{q_{bi}} \pi_{bi} = q_{bi}\left(p_{bi} - c_{bi}\right) - \tfrac{1}{2}\eta_{bi}q_{bi}^{2} - F_{bi} \quad \forall i \in I \tag{4}$$

Table 3 A list of mathematical notations of the mixed-integer nonlinear model

Notations:	
b	Indicates biofuel
f	Indicates oil fuels
I	Index of bio-refineries which Indicates refinery number ($i \in I$)
Parameters:	
F_{bi}	Fixed set-up cost of bio-refinery i
F_f	The fixed set-up cost for oil refinery
c_{bi}	Production cost per unit of biofuel at bio-refinery i
c_f	Cost of production per unit of oil fuel
cap_{bi}	The capacity of bio-refinery i
cap_f	The capacity of oil refinery
α_{bi}	The maximum base price of biofuel for bio-refinery i (Depending on the maximum biofuel demand and the minimum production of it)
α_f	The maximum base price of oil fuel (Depending on the maximum oil fuel demand and the minimum production of it)
β_{bi}	The biofuel price sensitivity coefficient against its production for bio-refinery i (it means that the biofuel price of a bio-refinery will decrease as production increases)
$\beta_{bii\prime}$	Biofuel price sensitivity coefficient for bio-refinery i compared to the production of other bio-refineries
β_{fi}	oil fuel price sensitivity coefficient compared to the production of biofuels
γ_{bi}	Biofuel price sensitivity coefficient of bio-refinery i relative to oil fuel production
γ_f	The oil fuel price sensitivity coefficient relative to its production
η_{bi}	The variable cost coefficient of production of bio-refinery i
η_f	Variable cost coefficient of production for oil refinery
ε_{bi}	The coefficient of converting government investment into the capacity of bio-refinery i
ε_f	The coefficient of converting government investment into the capacity of oil refineries
d	Total market demand for fuel
θ_f	Pollution emission level caused by the consumption of each unit of oil fuel
θ_{bi}	The pollution emission level of bio-refinery i caused by the consumption of its biofuel unit
ρ_{bi}	Pollutant emission level resulting from the activity of bio-refinery i to produce a biofuel unit
ρ_f	Pollutant emission levels resulting from refinery activity to produce a oil fuel unit
Ψ_f	The social welfare due to the production of each oil fuel unit
Ψ_{bi}	Social welfare due to the production of each biofuel unit in a bio-refinery i
π_{bi}	Minimum expected profit of a bio-refinery i
$\bar{\pi}_f$	Minimum expected profit of oil refinery
$\bar{B}udget$	Maximum budget of the government
Decision Variables:	
q_{bi}	The amount of production of bio-refinery i
q_f	The amount of oil fuel production
Δcap_{bi}	Increased capacity of bio-refinery i
Δcap_f	Increased capacity of oil refinery
I_{bi}	The amount of government investment on bio-refinery i
I_f	The amount of government investment on oil refinery
t_{bi}	Government tariff rate (as tax or subsidy) per unit of production in bio-refinery i
t_f	Government tariff rate (as tax or subsidy) per unit of production in oil refinery
x_j	Binary variable: Government strategy of type j $j = 1, 2$

s.t:

$$q_{bi} \leq cap_{bi} \ \forall i \in I \tag{5}$$

$$q_{bi} \geq 0 \ \forall i \in I \tag{6}$$

Oil refinery:

$$\max_{q_f} \pi_f = q_f\left(p_f - c_f\right) - \frac{1}{2}\eta_f q_f^2 - F_f \tag{7}$$

s.t :

(8)

$$q_f \leq cap_f \tag{9}$$

$$q_f \geq 0 \tag{10}$$

The profit function of refineries is obtained from the difference between the income from the sale of fuel and its production costs. Moreover, the fixed setup cost, the production cost per unit, and the variable cost of production in each refinery are considered as costs of fuels. Furthermore, the production costs are quadratic. It means that the cost function turns quadratic if the variable factor has a declining rate of return. Total physical product is proportionate up to a certain amount and then stops being so. As a result, the variable factor's marginal physical product will decrease. And marginal physical product will not be positive if Total physical product declines. In other words, there is a point beyond which additional increases in output cannot make. Costs can increase over this point, but production cannot. When no output is created, the total cost is equal to the fixed cost. The fixed cost, however, does not alter as production rises. As a result, variations in variable costs can be linked to increases in overall expenses. It should be noted that the area of declining returns to the variable factors is the main distinction between the linear and quadratic cost functions. Variable cost increases at a constant rate if the cost function is linear. Regardless of the firm's current level of production, it is quite plausible to presume that linear cost functions exist. In reality, variable costs increase due to the Law of Diminishing Returns' (or variable proportions') operation as output exceeds the short-term physical capacity limits of the available plant and equipment. Therefore, in our model, it is assumed that the variable cost of production increases as production increases. The objective functions of refineries are represented as relationships between Constraints (4) and (7), while Constraints (5) and (8) in refinery models indicate that the amount of production should not exceed the maximum capacity of the refinery, and Constraints (6) and (10) emphasize that the fuel should be produced.

4.4 Government policies

Government policies such as incentive schemes, play a significant role in industries, especially in the energy sector. The plans for the energy sector can be an investment for refineries that produce fuels with fewer pollutants and tariff is defined as subsidy or tax for them. In such cases, the objective of the government is to achieve sustainability conditions such as environmental issues and social welfare. In this research, it is assumed that the government uses two policies, tariff and investments in refineries to achieve its sustainability objectives. The government intervention policies about different types of refineries are shown in Fig. 3.

Tariff policy can be implemented as the first and second scenarios for both bio and oil refineries. Tariff policy is defined as tax and subsidy, which is related to the kind of fuel that is produced. The objective of the government is to achieve the highest social welfare with the lowest impact on the environment. According to the type of fuel that is provided, the government may offer subsidy or receive taxes.

The third and fourth scenarios are related to the investment of the government. In these scenarios, the government attempts to achieve its sustainability objectives by investing in refineries in order to increase its production capacity. As an incentive scheme, the government invests in refineries with less capacity but high quality. This encourages refineries to increase their production capacity and play an essential role in a competitive market.

Table 4 presents the model formulations of the scenarios. Models (11)–(18) are related to the formulations of the first and

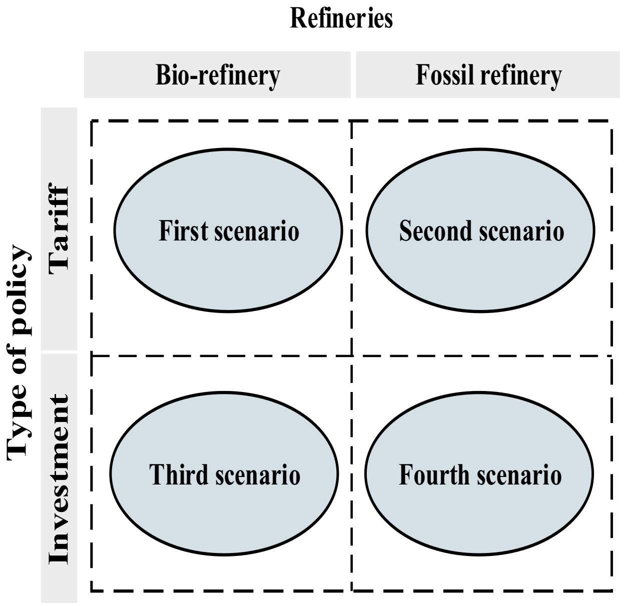

Fig. 3 Government Intervention Policies

Table 4 The mathematical models of refineries under government policies

Type of scenario	Tariff	Bio-refineries	$\pi_{bi}=q_{bi}\left(p_{bi}-c_{bi}-x_1t_{bi}\right)-\frac{1}{2}\eta_{bi}q_{bi}^2-F_{bi}\forall i\in I$	(11)
			$subjectedto:$	
			$q_{bi}\leq cap_{bi}\forall i\in I$	(12)
			$q_{bi}\geq 0\forall i\in I$	(13)
			$t_{bi}:Freeinthesign\forall i\in I$	(14)
		Oil refinery	$\pi_f=q_f\left(p_f-c_f-x_1t_f\right)-\frac{1}{2}\eta_fq_f^2-F_f$	(15)
			$subjectedto:$	
			$q_f\leq cap_f$	(16)
			$q_f\geq 0$	(17)
			$t_f:Freeinthesign$	(18)
	Capacity	Bio-refineries	$\pi_{bi}=q_{bi}\left(p_{bi}-c_{bi}\right)-\frac{1}{2}\eta_{bi}q_{bi}^2-F_{bi}\forall i\in I$	(19)
			$subjectedto:$	
			$q_{bi}\leq cap_{bi}+x_2\Delta cap_{bi}\forall i\in I$	(20)
			$\Delta cap_{bi}=\varepsilon_{bi}.I_{bi}\forall i\in I$	(21)
			$q_{bi},I_{bi},\Delta cap_{bi}\geq 0\forall i\in I$	(22)
		Oil refinery	$\pi_f=q_f\left(p_f-c_f\right)-\frac{1}{2}\eta_fq_f^2-F_f$	(23)
			$subjectedto:$	
			$q_f\leq cap_f+x_2\Delta cap_f$	(24)
			$\Delta cap_f=\varepsilon_f.I_f$	(25)
			$q_f,I_f,\Delta cap_f\geq 0$	(26)

second scenarios. In these models, t_{bi}, and t_{f} are considered as free decision variables in profit functions of refineries. If optimal values t_{bi} and t_{f} are positive, it means that the government offers a subsidy to refineries. On the contrary, a negative tariff would act as a tax that reduces the profit of refineries. Constraints (12) and (16) indicate the production capacity of refineries.

As a second policy, the government invests in refineries in order to increase their production capacity. Models (19)–(26) are related to the formulations of the third and fourth scenarios. Constraints (20), (21), (24), and (25) determine the increase in capacity if the investment policy is applied. The increase in capacity corresponds to the investment of the government can be converted into an additional capacity inserted at the right-hand side of constrains.

4.5 Mathematical model of the government

The government model attempts to achieve sustainability goals such as economic, social, and environmental goals. The mathematical model of the government will be as follows:

$$\boldsymbol{P}_1:maxGNR=x_1\left(\sum_i t_{bi}q_{bi}+t_fq_f\right)-x_2\left(\sum_i I_{bi}+I_f\right)\quad(27)$$

$$minEL=\sum_i\theta_{bi}q_{bi}+\theta_fq_f+\sum_i\rho_{bi}q_{bi}+\rho_fq_f\quad(28)$$

$$maxSW=\sum_i\Psi_{bi}q_{bi}+\Psi_fq_f\quad(29)$$

Subjected to:

$$Q_b+q_f\geq d\quad(30)$$

$$\pi_{bi}\geq\underline{\pi}_{bi}\ \forall i\in I\quad(31)$$

$$\pi_f\geq\underline{\pi}_f\quad(32)$$

$$GNR\geq -Budget\quad(33)$$

$$\sum_{j=1}^{2}x_j=1\quad(34)$$

$$t_{bi}:Free\ in\ the\ sign\ \forall i\in I\quad(35)$$

$$I_{bi}\geq 0\ \forall i\in I\quad(36)$$

$$t_f:Free\ in\ the\ sign\quad(37)$$

$$I_f\geq 0\quad(38)$$

$$x_j=0,1\ j=1,2\quad(39)$$

$$\boldsymbol{P}_2:\pi_{bi}=q_{bi}\left(p_{bi}-c_{bi}-x_1t_{bi}\right)-\frac{1}{2}\eta_{bi}q_{bi}^2-F_{bi}\forall i\in I\quad(40)$$

Subjected to:

$$q_{bi} \leq cap_{bi} + x_2 \Delta cap_{bi} \ \ \forall i \in I \tag{41}$$

$$\Delta cap_{bi} = \varepsilon_{bi}.I_{bi} \ \ \forall i \in I \tag{42}$$

$$q_{bi} \geq 0 \ \forall i \in I \tag{43}$$

$$\Delta cap_{bi} \geq 0 \ \forall i \in I \tag{44}$$

$$\pi_f = q_f\left(p_f - c_f - x_1 t_f\right) - \frac{1}{2}\eta_f q_f^2 - F_f \tag{45}$$

Subjected to:

$$q_f \leq cap_f + x_2 \Delta cap_f \tag{46}$$

$$\Delta cap_f = \varepsilon_f.I_f \tag{47}$$

$$q_f \geq 0 \tag{48}$$

$$\Delta cap_f \geq 0 \tag{49}$$

The economic objective function (27) represents the net revenue of the government regarding receipts or payments in different policies. According to the occurrence of policies, the net income of the government can be positive or negative. The aim of the environmental objective function (28) is to reduce the amount of pollutants from fuel consumption and refinery activities. It is assumed that the production and use of fuels cause pollutant emissions such as CO, CO_2, NO_2, particulate matter, etc. The social welfare objective function (29) maximizes social welfare from fuel production, fuel consumption, and job creation by activities of refineries.

Constraint (30) presents the production limitation of bio and oil fuels. It ensures that the production of refineries should be higher than the total market demand which means that the market demand should be fulfilled. Constraints (31) and (32) guarantee that the profit of the bio and oil refineries should be higher than the minimum expected profit. Constraint (33) is related to the net revenue of the government, and it means that GNR should not be more than the available budget. $x_1 = 1$ and $x_2 = 2$, respectively, indicate the adoption of the first and second policies by the government. Therefore, according to the occurrence of each strategy, the net revenue of the government can be positive or negative. Constraint (34) shows that only one policy can be implemented.

Finally, the model (27)–(49) represents the formulation of a bi-level multi-objective mixed-integer nonlinear programming model considering the government strategies and competition between refineries. In the presented bi-level model, decision variables of the refineries and the government are indicated in their corresponding functions. In the refineries model, the objective function and constraints are nonlinear functions regarding the decision variables. Also, the government model is nonlinear programming problem.

Bi-Level Programming Problem (BLP) is one of the most significant problems in decision theory that is a subset of multilevel programming problems. This problem has two levels, outer and inner, where the answer space of the first level is determined by the second level. The conventional method for solving the two-level programming problem is a transformation approach based on optimal Karush-Kahn-Tucker (KKT) conditions or fines functions (Chalmardi and Camacho-Vallejo 2019). In this paper, we apply the KKT approach. Finally, to solve the multi-objective single-level problem, we used the revised multi-choice goal programming (MCGP) approach to consider the importance of functions.

5 Solution approach

As a solution approach, we used the transformation and revised MCGP approaches, which are mentioned in the following section.

5.1 Transformation approach

In order to convert the lower-level problem into the constraint of the upper level, the transformation approach uses the KKT optimality condition. Thus, this nested optimization problem is reduced to the traditional one-level nonlinear programming problem, which is non-convex.

In the current bi-level programming problem, the government plays a leading role, and refineries at the second level are considered as the followers. Thus, there is a non-cooperative competition between them. In this competition, the refineries attempt to achieve a suitable amount of production, such that the profit of each refinery is maximized. We will try to obtain the optimal values of this competition according to the competitive Cournot model. First, we should prove the concavity of the lower-level problems to achieve equilibrium values. Moreover, π_{bi} and π_{f} are concave if and only if their second derivatives are negative. The proof is provided as follows.

By substituting the price functions into the profit functions of each refinery and examining optimality conditions, i.e., the first and second derivatives, we obtain the following results:

$$\frac{\partial \pi_{bi}}{\partial q_{bi}} = \alpha_{bi} - 2\beta_{bi} q_{bi} - \sum_{\acute{i}\prime} \beta_{bii'} q_{bi'} + \gamma_{bi} q_f - x_1 t_{bi} - c_{bi} - \eta_{bi} q_{bi} \tag{50}$$

$$\frac{\partial^2 \pi_{bi}}{\partial q_{bi}^2} = -2\beta_{bi} - \eta_{bi} \tag{51}$$

Moreover,

$$\frac{\partial \pi_f}{\partial q_f} = \alpha_f + \sum\nolimits_i \beta_{fi} q_{bi} - 2\gamma_f q_f - c_f - x_1 t_f - \eta_f q_f \tag{52}$$

$$\frac{\partial^2 \pi_f}{\partial q_f^2} = -2\gamma_f - \eta_f \tag{53}$$

The functions π_{bi} and π_{f} are concave functions with respect to q_{bi} and q_f, respectively. Therefore, the Kuhn–Tucker conditions, which are the optimality conditions, can now be applied to them. The best response of each refinery was obtained by examining the optimal conditions at the second level of the model. The Kuhn–Tucker conditions for the maximization problem will be considered as the best response of each player (Bazaraa et al. 2006). Next, we added the best response of each refinery to the first level as a constraint to convert the bi-level model to a single-level one. The model is obtained as follows:

$$\max GNR = x_1\Big(\sum_i t_{bi} q_{bi} + t_f q_f\Big) - x_2\Big(\sum_i I_{bi} + I_f\Big) \tag{54}$$

$$minEI = \sum_i \theta_{bi} q_{bi} + \theta_f q_f + \sum_i \rho_{bi} q_{bi} + \rho_f q_f \tag{55}$$

$$maxSW = \sum_i \Psi_{bi} q_{bi} + \Psi_f q_f \tag{56}$$

Subjected to:

$$Q_b + q_f \geq d \tag{57}$$

$$\pi_{bi} \geq \underline{\pi}_{bi} \;\; \forall i \in I \tag{58}$$

$$\pi_f \geq \underline{\pi}_f \tag{59}$$

$$GNR \geq -Budget \tag{60}$$

$$\sum_{j=1}^{2} x_i = 1 \tag{61}$$

$$q_{bi} - cap_{bi} - x_2 \varepsilon_{bi}.I_{bi} \leq 0 \forall i \in I \tag{62}$$

$$\lambda_{bi}\left(cap_{bi} + x_2 \varepsilon_{bi}.I_{bi} - q_{bi}\right) = 0 \forall i \in I \tag{63}$$

$$\begin{aligned}&\alpha_{bi} - 2\beta_{bi} q_{bi} - \sum_{i\prime} \beta_{bii\prime} q_{bi\prime} + \gamma_{bi} q_f - x_1 t_{bi} - c_{bi} \\ &\quad - \eta_{bi} q_{bi} - \lambda_{bi}(+1) = 0 \forall i \in I\end{aligned} \tag{64}$$

$$\lambda_{bi} \geq 0 \;\; \forall i \in I \tag{65}$$

$$q_f - cap_f - x_2 \varepsilon_f.I_f \leq 0 \tag{66}$$

$$\lambda_f\left(cap_f + x_2 \varepsilon_f.I_f - q_f\right) = 0 \tag{67}$$

$$\alpha_f + \sum_i \beta_{fi} q_{bi} - 2\gamma_f q_f - c_f - x_1 t_f - \eta_f q_f - \lambda_f(+1) = 0 \tag{68}$$

$$\lambda_f \geq 0 \tag{69}$$

$$q_{bi}, q_f, I_{bi}, I_f \geq 0 \tag{70}$$

$$x_j = 0, 1 \tag{71}$$

$$t_{bi}, t_f \;:\; Free\ in\ the\ sign \tag{72}$$

Where, the constraints (62)-(69) are related to KKT conditions in refinery models.

5.2 Revised multi-choice goal programming

One of the most important methods for solving multi-objective programming problems is goal programming. This method can consider different goals and allows deviations from them so that it can provide flexibility in decision-making processes as compared to linear programming. Standard attitudes of the goal programming model emphasize finding a solution close to the expected level of each objective function and minimize deviations from the expected level of any of them. Based on available information and resource constraints, in practice, it is so difficult for decision-makers to set an initial conservative expectation level for each objective function. In order to overcome such problems, Chang (2008) proposed a new approach, which is called the revised MCGP model, for multi-objective decision-making problems with multiple levels of expectation for each goal.

We try to minimize deviations from the lower or upper limit of expectation levels using continuous variables for each ideal and depending on the type of problem. We require knowing the kinds of goals in order to make a model. The following two modes are suggested for them.

In the first state, if the goal is "the more," "the better" the model will be as shown below:

$$Min \sum\nolimits_{n=1}^{N} [w_n(d_n^+ + d_n^-) + v_n(e_n^+ + e_n^-)] \tag{73}$$

$s.t$:

$$h_k(x) = (\leq or \geq) \tag{74}$$

$$f_n(x) - d_n^+ + d_n^- = y_n \quad n = 1, 2, \dots, N \tag{75}$$

$$y_n - e_n^+ + e_n^- = g_{n.max} \quad n = 1, 2, \dots, N \tag{76}$$

$$g_{n.min} \leq y_n \leq g_{n.max} \quad n = 1, 2, \dots, N \tag{77}$$

$$d_n^+, d_n^-, e_n^+, e_n^- \geq 0 \quad n = 1, 2, \dots, N \tag{78}$$

In the second state, if the goal is "the less," "the better" the model will be as shown below:

$$Min \sum_{n=1}^{N} [w_n(d_n^+ + d_n^-) + v_n(e_n^+ + e_n^-)] \tag{79}$$

$s.t$:

$$h_k(x) = (\leq or \geq) \tag{80}$$

$$f_n(x) - d_n^+ + d_n^- = y_n \quad n = 1, 2, \dots, N \tag{81}$$

$$y_n - e_n^+ + e_n^- = g_{n.min} \quad n = 1, 2, \dots, N \tag{82}$$

$$g_{n.min} \leq y_n \leq g_{n.max} \quad n = 1, 2, \dots, N \tag{83}$$

$$d_n^+, d_n^-, e_n^+, e_n^- \geq 0 \quad n = 1, 2, \dots, N \tag{84}$$

In the above relationships, $g_{n.\min}$ and $g_{n.\max}$ are the lower limit and the upper limit of expectations of the desired goals, respectively; y_n is a continuous variable with a range of $g_{n.\min} \leq y_n \leq g_{n.\max}$; w_n is the weight attached to the nth goal; v_n is a weight of the sum of positive and negative deviations of variable y_n from expected levels; and d_n^+andd_n^- are the positive and negative deviations, respectively, from $|f_n(x) - y_n|$. For the first state, e_n^+ande_n^- are the positive and negative deviations from $|y_n - g_{n.\max}|$, and for the second state, they are the deviations from $|y_n - g_{n.\min}|$.

In planning and policymaking in the field of social and economic issues, goals are usually macro and multiple. The MCGP helps decision-makers to set multi-choice expectation levels for each goal in order to avoid underestimating the decision. The revised MCGP approach does not include multiple binary variables for modeling the various aspiration levels. This makes it easier for industrial participants and policy-makers to incorporate using common linear programming packages, and more comfortable to understand. The revised MCGP approach for the presented problem (54)–(72) formulated as follows:

$$\begin{aligned} Minz = & \left(\frac{w_1}{GNR_{max} - GNR_{min}} \right) (d_1^+ + d_1^-) \\ & + \left(\frac{v_1}{GNR_{max} - GNR_{min}} \right) (e_1^+ + e_1^-) \\ & + \left(\frac{w_2}{EI_{max} - EI_{min}} \right) (d_2^+ + d_2^-) \\ & + \left(\frac{v_2}{EI_{max} - EI_{min}} \right) (e_2^+ + e_2^-) \\ & + \left(\frac{w_3}{SW_{max} - SW_{min}} \right) (d_3^+ + d_3^-) \\ & + \left(\frac{v_3}{SW_{max} - SW_{min}} \right) (e_3^+ + e_3^-); \end{aligned} \tag{85}$$

$s.t$:

Constraints (57)-(72)

$$GNR - d_1^+ + d_1^- = y_1; \tag{86}$$

$$y_1 - e_1^+ + e_1^- = GNR_{max}; \tag{87}$$

$$GNR_{min} \leq y_1 \leq GNR_{max}; \tag{88}$$

$$EI - d_2^+ + d_2^- = y_2; \tag{89}$$

$$y_2 - e_2^+ + e_2^- = EI_{min}; \tag{90}$$

$$EI_{min} \leq y_2 \leq EI_{max}; \tag{91}$$

$$SW - d_3^+ + d_3^- = y_3; \tag{92}$$

$$y_3 - e_3^+ + e_3^- = SW_{max}; \tag{93}$$

$$SW_{min} \leq y_3 \leq SW_{max}; \tag{94}$$

$$GNR \leq GNR_{max}; \tag{95}$$

$$GNR \geq GNR_{min}; \tag{96}$$

$$EI \leq EI_{max}; \tag{97}$$

$$EI \geq EI_{min}; \tag{98}$$

$$SW \leq SW_{max}; \tag{99}$$

$$SW \geq SW_{min}; \tag{100}$$

$$d_1^+, d_1^-, d_2^+, d_2^-, d_3^+, d_3^-, e_1^+, e_1^-, e_2^+, e_2^-, e_3^+, e_3^-, \geq 0. \tag{101}$$

The objective function of the revised MCGP determines the degree of deviation from the ideals. In our proposed model, ideals are economic, social, and environmental goals, which we attempt to minimize the deviation from those ideals by regarding the minimum and maximum expected level of aspirations by taking in to account the policy-makers views. As mentioned in the problem description, the model will be completed by replacing GNR, EI, and SW in constraints and adding constraints (57)–(72).

6 A numerical example and case study

In this section, we first provide a brief description of energy conservation and explain the role of government in controlling air pollution, which is caused by fuel consumption, especially in the transportation sector.

The use of fossil fuels is responsible for the continuous increase in the levels of carbon dioxide in the atmosphere. If we could stop using fossil fuels, the level of carbon dioxide in the atmosphere would stop increasing (Quadrelli and Peterson 2007). Most of the transport utilities are powered by diesel and gasoline that burn petroleum for generating energy. These are the primary contributors to air pollution and the most challenging issues to manage (Braungardt et al. 2019). Biofuels are considered a partial solution because the use of fossil fuels is reduced by using biofuels. The advantages of using biofuels are that they are renewable, unlike fossil fuels, they have a lower carbon footprint, and they are often cheaper as compared to fossil fuels. All biofuels are tried to be converted into carbon neutral. They decrease greenhouse gas emissions as compared to standard transport fuels (Kristianto and Zhu 2019; Rowe et al. 2009).

Land and climate diversity of Iran make the cultivation of a range of energy crops suitable for the production of liquid biofuels. Nowadays, molasses from sugar cane and sugar beet are the easily and readily available biofuel feedstock for bioethanol production in Iran. Moreover, there are about 17.86 million tons of plant waste that could produce nearly 5 billion liters of bioethanol annually. For spark-ignition engine vehicles, the volume of bioethanol is sufficient to conduct E10 in Iran by 2026. Energy plants such as cellulosic materials and algae also have tremendous potential to be cultivated. Furthermore, 7% of the territory of Iran is protected by forest products that are considered to be suitable sources of liquid biofuels such as bioethanol and biodiesel (Ghobadian 2012; Hassanzadeh 2018).

Among fossil fuels, diesel has a significant share of the consumption of petroleum products. Because of low diesel prices, high subsidies, and an inappropriate pattern of use, the demand for diesel has significantly grown in Iran. This growth imposed 2.2 billion liters of imports during the period 2006–2007, which was equivalent to 7.5% of diesel production, and the cost was about $1.2 billion in 2007. Consequently, the government implemented fuel rationing in 2007, and a targeted subsidy law in 2010. However, these attempts have not gained effective control of consumption because of the extensive variation between global diesel prices and domestic costs. After the introduction of fuel rationing and the targeted subsidy law in 2011, diesel imports levied 3.6 billion liters of imports, and the cost was around $2.2 billion (Ghorbani et al. 2018). Therefore, the government requires implementing new approaches and policies for resolving and monitoring the negative impacts of economic and environmental factors. As another supplementary solution, third-generation fuels, biofuels, are considered to be capable of reducing the petroleum requirement (Ahmadian et al. 2007).

Governments can take many actions to reduce the impacts of these kinds of pollutants. For increasing the capacity of refineries, strategies such as tariff and investment that produce fewer pollutants can be useful as an incentive plan in a competitive form between bio and oil refineries.

For displaying the validation of the proposed model, we provided a case study and examined the sensitivity of the model by performing a sensitivity analysis on some parameters. In order to investigate the results of the model, we consider three bio-refineries that produce biofuels with different quality standards that influence the market price. Given the number of cars available and the average usage per day, the fuel demand was calculated. The fixed set up cost for refineries is also based on the daily equivalent of the annual operating cost and initial investment. The capacity of the refineries is based on the daily production rate and the cost of fuel production in the refineries per liter. Also, we have obtained the other required data based on interviews from fuel production managers as well as experts in this field (Ghobadian 2012).

According to the reports and statistics, there are 24 million cars in Iran, and the average consumption is 2.5 L of fuel per day for each vehicle. Therefore, the amount of fuel demand per day will be 60 million. In the following, we will try to justify the parameters of a model for refineries. Fixed set-up cost of refineries is based on the daily equivalent of the annual operating cost and initial investment. The limited production capacity of biofuel refineries in Iran has caused the price of these fuels to be higher than fossil fuels. The cost of production per unit of them depends on the production capacity and the fixed set-up costs for refineries (Ghobadian 2012; Hassanzadeh 2018).

α is the maximum base price of fuel for refineries depends on the maximum fuel demand and minimum production, which is higher for biofuels than fossil fuels. The fuels' price sensitivity coefficients ($\beta and \gamma$) have considered in relation to both their own and other refineries' production. By studying articles in this field and the models presented, these coefficients and variable cost coefficient of production for refineries included values close to zero (Bárcena-Ruiz and Espinosa 1999; Goering 2007; Xia et al. 2013).

The values of the coefficient of converting government investment into the capacity of refineries are approximately close to the ratio of the production capacity of refineries to setup cost. $\theta and \rho$ are the pollution emission level which is caused by the consumption of each unit of oil and biofuels and activity of refineries. According to the literature review, since consuming biofuels and the activity of bio-refineries produce fewer pollutants than consuming oil fuels, the value of the pollution emission level should be considered as lower for biofuels. Also, the value of social welfare of biofuels are considered more than oil fuels (Shabani et al. 2014; Perrin et al. 2008; Blumstein 2010; Vine 2008).

The following factors are considered as the parameters of our proposed model (Table 5).

It is assumed that the government can implement one of the two types of policies at a time. The implementation of any of the policies will influence the net revenue of the government and the expected profit of refineries. Therefore, it is very essential to take accurate decisions on the amount of the tariff or the amount of investment. The obtained results tested in the constraints to evaluate the performance of the proposed model. With the establishment of all relations, the validity of the model was determined. Also, the obtained results, such as fuel price, the amount of the tariff, and the amount of investment, are close to the actual values, which are reasonable according to the opinion of the experts in this field. Considering government policies and the competition between bio and oil refineries, the optimal values of the mathematical model are presented in Table 6. The results of the model demonstrate that when the budget of the government is high, and the refineries do not have enough capacity, thus, the second policy should be applied, which increases their capacities by using the government budget. In our mentioned example, applying tariff policy means that the government offers a subsidy to refineries for each liter of production with fewer pollutants and receives tax from refineries per liter of production with higher pollution. The net revenue of the government decreases by offering subsidy or investing in refineries, but the amount of production and the expected profit of refineries improve.

A sensitivity analysis is now conducted below on some parameters of the model. The results of the sensitivity analysis on demand and cap_{b1} are shown in Table 7. The impact of demand on the objective functions of the government is shown in Fig. 4. It can be concluded from the figures that the increase in demand shows a direct impact on social welfare and environmental objectives. As shown in Fig. 4a, when a tariff policy is performed, the net revenue of the government becomes the fixed amount that is related to the maximum value in the revised MCGP model. In this case,

Table 5 The value of parameters

Parameters	Value of parameters
F_{bi}, F_f	F_{b1}=1.20E+6, F_{b2}= 1.25E+6, F_{b3}= 1.32E+6, F_f= 9.50E+5
c_{bi}, c_f	$c_{b1} = 0.91, c_{b2} = 0.84, c_{b3} = 0.96, c_f = 0.46$
cap_{bi}, cap_f	$cap_{b1} = 1.35\text{E}+7$, $cap_{b1} = 1.32\text{E}+7, cap_{b1} = 1.33\text{E}+7, cap_f = 2\text{E}+7$
α_{bi}, α_f	$\alpha_{b1} = 2.25, \alpha_{b2} = 2.18, \alpha_{b3} = 2.14, \alpha_f = 1.3$
β_{bi}	$\beta_{b1} = 2.2E-8, \beta_{b2} = 2.5E-8, \beta_{b3} = 3.2E-8$
$\beta_{bii'}$	$\beta_{b12} = \beta_{b13} = \beta_{b21} = \beta_{b23} = \beta_{b31} = \beta_{b32} = 8E-9$
β_{fi}	$\beta_{f1} = 4E-9, \beta_{f2} = 5E-9, \beta_{f3} = 4E-9$
γ_{bi}, γ_f	$\gamma_{b1} = 4E-9, \gamma_{b2} = 5E-9, \gamma_{b3} = 4E-9, \gamma_f = 1.2E-8$
η_{bi}, η_f	$\eta_{b1} = 9.5E-9, \eta_{b2} = 9.5E-9, \eta_{b3} = 9.5E-9, \eta_f = 7.5E-9$
$\varepsilon_{bi}, \varepsilon_f$	$\varepsilon_{b1} = 14.5, \varepsilon_{b2} = 15, \varepsilon_{b3} = 15.5, \varepsilon_f = 20.5$
d	60000000
θ_{bi}, θ_f	$\theta_{b1} = 0.0075, \theta_{b2} = 0.0082, \theta_{b3} = 0.0079, \theta_f = 0.0182$
ρ_{bi}, ρ_f	$\rho_{b1} = 0.0055, \rho_{b2} = 0.0060, \rho_{b3} = 0.0050, \rho_f = 0.0045$
Ψ_{bi}, Ψ_f	$\Psi_{b1} = 0.50, \Psi_{b2} = 0.55, \Psi_{b3} = 0.60, \Psi_f = 0.45$
$\underline{\pi}_{bi}, \underline{\pi}_f$	$\underline{\pi}_{b1} = 21500, \underline{\pi}_{b2} = 22000, \underline{\pi}_{b3} = 21800, \underline{\pi}_f = 24000$
$Budget$	500000
w_i, v_i	$w_1 = 0.333, w_2 = 0.334, w_3 = 0.333, v_1 = 0.333, v_2 = 0.334, v_3 = 0.333$
GNR_{max}, GNR_{min}	$GNR_{max} = 100000, GNR_{min} = -500000$
EI_{max}, EI_{min}	$EI_{max} = 1800000, EI_{min} = 1$
SW_{max}, SW_{min}	$SW_{max} = 1E+10, SW_{min} = 1$

Table 6 The optimal value of variables

Variables	The optimal value of Variables
q_{bi}, q_f	$q_{b1} = 13500000, q_{b2} = 13200000, q_{b3} = 13300000, q_f = 20000000$
$\Delta cap_{bi}, \Delta cap_f$	$\Delta cap_{b1} = 0, \Delta cap_{b2} = 0, \Delta cap_{b3} = 0, \Delta cap_f = 0$
I_{bi}, I_f	$I_{b1} = 0, I_{b2} = 0, I_{b3} = 0, I_f = 0$
t_{bi}, t_f	$t_{b1} = -0.893, t_{b2} = 0.44, t_{b3} = -0.099, t_f = 0.383$
p_{bi}, p_f	$p_{b1} = 1.821, p_{b2} = 1.736, p_{b3} = 1.581, p_f = 1.233$
x_j	$x_1 = 1, x_2 = 0$
λ_{bi}, λ_f	$\lambda_{b1} = 1.379, \lambda_{b2} = 0, \lambda_{b3} = 0.218, \lambda_f = 0$
d_n^+, d_n^-	$d_1^+ = 0, d_1^- = 0, d_2^+ = 988510, d_2^- = 0, d_3^+ = 0, d_3^- = 9.97\text{E}+9$
e_n^+, e_n^-	$e_1^+ = 0, e_1^- = 0, e_2^+ = 0, e_2^- = 0, e_3^+ = 0, e_3^- = 0$
$z = 0.515, \text{GNR} = 100000, \text{EI} = 988510, \text{SW} = 30990000$	

when the government offers a subsidy to any refineries, it decreases the government's net revenue, and the tax that is received also has a direct impact on GNR. Therefore, this balance in offering subsidy and receiving tax from refineries makes the GNR function take the maximum value in the revised MCGP approach. As clearly illustrated in the figure, to increase the capacity of the refineries, the investment of the government shows a significant impact on GNR.

Figure 5 is related to the sensitivity of the optimal amount of the government objective functions by considering different values of cap_{b1}. In Fig. 4a, it is illustrated that the GNR is sensitive to the capacity investment policy and decreases the net revenue of the government. In Fig. 5b, it is shown that the EI objective function descends by increasing the capacity of bio-refineries. On the other hand, an increase in the capacity of refineries attributes to the highest social welfare, especially during the implementation of a tariff policy.

7 Discussions and managerial insights:

This research studies the impact of government interventions on the production quantities of refineries considering competition between bio and oil fuels. Also, our study has discussed the issue based on the sustainability goals of the government in the contexts of economic, environmental, and social aspects considering the selection of the tariff or investment strategy. Although some papers have focused on the tariff policy as a subsidy or a tax scheme (Nicoletti and You 2020; Zhang and Yousaf 2020), there is still a lack of models taking the government's role as an independent player in the competitive market of refineries into account. Therefore, we developed a bi-level multi-objective mathematical model incorporating two policies of tariff and investment on production capacity as environmental governance policy in refineries competition to fill these research gaps.

The effect of various parameters on the optimal production rate, government tariff rate, and some performance measures was evaluated. Therefore, the numerical example and sensitivity analysis provide some important managerial insights, which are discussed as follows:

- According to Fig. 5a, if the government applies the tariff policy by increasing the capacity up to a threshold, it can increase the amount of GNR. This threshold is determined by the model, so according to the threshold determined by the model, it is recommended to the management to increase the capacity to a certain extent, and increasing it beyond that limit will not affect the GNR.
- Figures. 4b and 5b show that with the application of the tariff policy, if the capacity and demand increase, the objective function of the environmental impact will decrease. Therefore, it recommended that the tarrif policy can apply by the management in order to reduce pollution and achieve environmental goals.
- According to Fig. 4c, it can be seen that with the increase in demand for both policies, the amount of social welfare increases, but in the case that the government chooses the capacity increase policy, from one point on, the amount of social welfare decreases with the increase in demand. This point or threshold is determined by the model. In such a situation, according to Fig. 5c, the management can compensate for this decrease by increasing the capacity of the bio-refinery to achieve the social welfare goal.
- According to Table 7, by increasing the capacity of the bio-refinery, we move from increasing the capacity policy (j = 2) to the policy of applying the tariff (j = 1). Therefore, it is recommended to the management that if they want to increase the capacity in order to accomplish their sustainability objectives, as stated in Fig. 5, they should implement the tariff policy.
- The governments play a significant role in encouraging refineries to produce fuels with fewer pollutants such as biofuels. In this way, the policies of governments, such as incentive plans, can be viewed as valuable. In hav-

Table 7 Sensitivity analysis of demand and$\boldsymbol{cap_{b1}}$

The effect of demand change on the values of variables and objective functions

$\boldsymbol{d}$	q_{b1}	q_{b2}	q_{b3}	q_f	p_{b1}	p_{b2}	p_{b3}	p_f	t_{b1}	t_{b2}	t_{b3}	t_f	x_1	x_2	Δcap_{b1}	Δcap_{b2}	Δcap_{b3}	Δcap_f
5.5E+7	1.4E+7	1.3E+7	1.3E+7	1.5E+7	1.80	1.71	1.56	1.29	-0.93	0.25	0.10	0.54	1	0	0.00	0.00	0.00	0.00
5.6E+7	1.4E+7	1.3E+7	1.3E+7	1.6E+7	1.81	1.72	1.57	1.28	0.47	0.42	-1.49	0.51	1	0	0.00	0.00	0.00	0.00
5.7E+7	1.4E+7	1.3E+7	1.3E+7	1.7E+7	1.81	1.72	1.57	1.27	0.00	0.43	-1.03	0.48	1	0	0.00	0.00	0.00	0.00
5.8E+7	1.3E+7	1.3E+7	1.3E+7	1.8E+7	1.81	1.73	1.57	1.26	0.48	0.35	-1.42	0.45	1	0	0.00	0.00	1.10	0.00
5.9E+7	1.4E+7	1.3E+7	1.3E+7	1.9E+7	1.82	1.73	1.58	1.25	0.24	0.44	-1.26	0.42	1	0	0.00	0.00	0.00	0.00
6.0E+7	1.4E+7	1.3E+7	1.3E+7	2.0E+7	1.82	1.74	1.58	1.23	-0.89	0.44	-0.10	0.38	1	0	0.00	0.00	0.00	0.00
6.1E+7	1.4E+7	1.3E+7	1.3E+7	2.1E+7	1.83	1.74	1.59	1.22	0.00	0.00	0.00	0.00	0	1	0.00	0.00	0.00	1.0E+6
6.2E+7	1.4E+7	1.3E+7	1.3E+7	2.2E+7	1.83	1.75	1.59	1.21	0.00	0.00	0.00	0.00	0	1	0.00	0.00	7.1E+4	1.9E+6
6.3E+7	1.3E+7	1.3E+7	2.3E+7	2.0E+7	1.75	1.67	1.28	1.27	5.3E+4	4.9E+4	-7.2E+4	1.9E+4	0	1	0.00	0.00	9.5E+6	0.00
6.4E+7	1.2E+7	1.0E+7	1.9E+7	2.9E+7	1.87	1.83	1.48	1.12	6.4E+5	7.2E+5	-2.2E+5	8.6E+4	0	1	1.6E+8	0.00	5.3E+6	9.2E+6
6.5E+7	1.4E+7	1.3E+7	1.3E+7	2.5E+7	1.84	1.76	1.60	1.17	0.00	0.00	0.00	0.00	0	1	0.00	0.00	0.00	5.0E+6

The effect of$\boldsymbol{cap_{b1}}$change on the values of variables and objective functions

$\boldsymbol{cap_{b1}}$	q_{b1}	q_{b2}	q_{b3}	q_f	p_{b1}	p_{b2}	p_{b3}	p_f	t_{b1}	t_{b2}	t_{b3}	t_f	x_1	x_2	Δcap_{b1}	Δcap_{b2}	Δcap_{b3}	Δcap_f
1.30E+7	1.3E+7	1.3E+7	1.3E+7	2.1E+7	1.83	1.74	1.59	1.23	0.00	0.00	0.00	0.00	0	1	0.00	0.00	0.00	5.0E+5
1.31E+7	1.3E+7	1.3E+7	1.3E+7	2.0E+7	1.83	1.74	1.59	1.23	0.00	0.00	0.00	0.00	0	1	0.00	0.00	0.00	4.0E+5
1.32E+7	1.3E+7	1.3E+7	1.3E+7	2.0E+7	1.83	1.74	1.58	1.23	0.00	0.00	0.00	0.00	0	1	0.00	0.00	0.00	3.0E+5
1.33E+7	1.3E+7	1.3E+7	1.3E+7	2.0E+7	1.83	1.74	1.58	1.23	0.00	0.00	0.00	0.00	0	1	0.00	0.00	0.00	2.0E+5
1.34E+7	1.3E+7	1.3E+7	1.3E+7	2.0E+7	1.82	1.74	1.58	1.23	0.00	0.00	0.00	0.00	0	1	0.00	0.00	0.00	1.0E+5
1.35E+7	1.4E+7	1.3E+7	1.3E+7	2.0E+7	1.82	1.74	1.58	1.23	-0.89	0.44	-0.10	0.38	1	0	0.00	0.00	0.00	0.00
1.36E+7	1.4E+7	1.3E+7	1.3E+7	2.0E+7	1.82	1.73	1.58	1.24	0.01	-0.59	0.01	0.39	1	0	0.00	0.00	0.00	0.00
1.37E+7	1.4E+7	1.3E+7	1.3E+7	2.0E+7	1.82	1.73	1.58	1.24	0.47	0.44	-1.50	0.39	1	0	33.83	34.99	3.6E+1	4.8E+1
1.38E+7	1.4E+7	1.3E+7	1.3E+7	2.0E+7	1.81	1.73	1.58	1.24	-1.1E+0	4.4E-1	1.2E-1	3.9E-1	1	0	0.00	0.00	0.00	0.00
1.39E+7	1.4E+7	1.3E+7	1.3E+7	2.0E+7	1.81	1.73	1.58	1.24	4.6E-1	-9.4E-1	-1.3E-1	4.0E-1	1	0	0.00	0.00	0.00	0.00

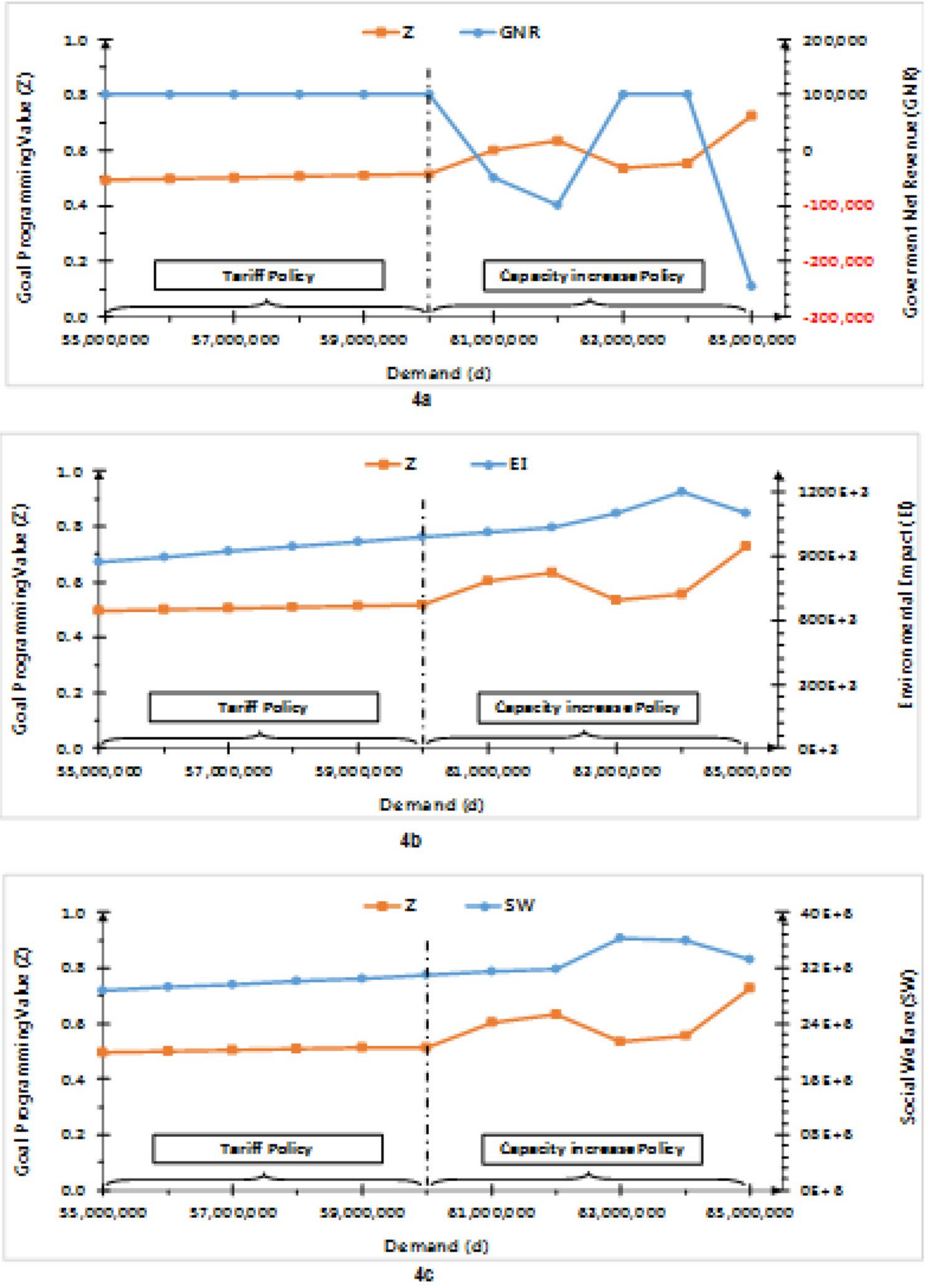

Fig. 4 The sensitivity of the optimal value of the government objective functions according to different amounts of demand

ing financial support from refineries and obtaining sustainability factors, the policy of tariff and investment in refineries that produce fuel with fewer pollutants can be remarkable.

- Appropriate budget allocation and the optimal quantification of tariff and investment strategies by the government can achieve a higher level of social welfare. Therefore, the optimal allocation of budget for financial support of refineries is essential.
- The tariff strategy exhibits a significant impact on the profit of refineries, and the investment policy displays a considerable effect on the net revenue of the government by improving the capacity of refineries. Therefore, the best value of tariff per unit of production and the amount of investment in each unit of production play significant roles in reaching sustainability aspects.
- Proper energy policy to achieve sustainable development goals requires a diverse range of political, economic, social, and environmental considerations. Determining the best priority for objective functions of the government shows notable performance in achieving the optimal values. Therefore, it is essential to apply the best coefficients for objective functions in reaching ideals.

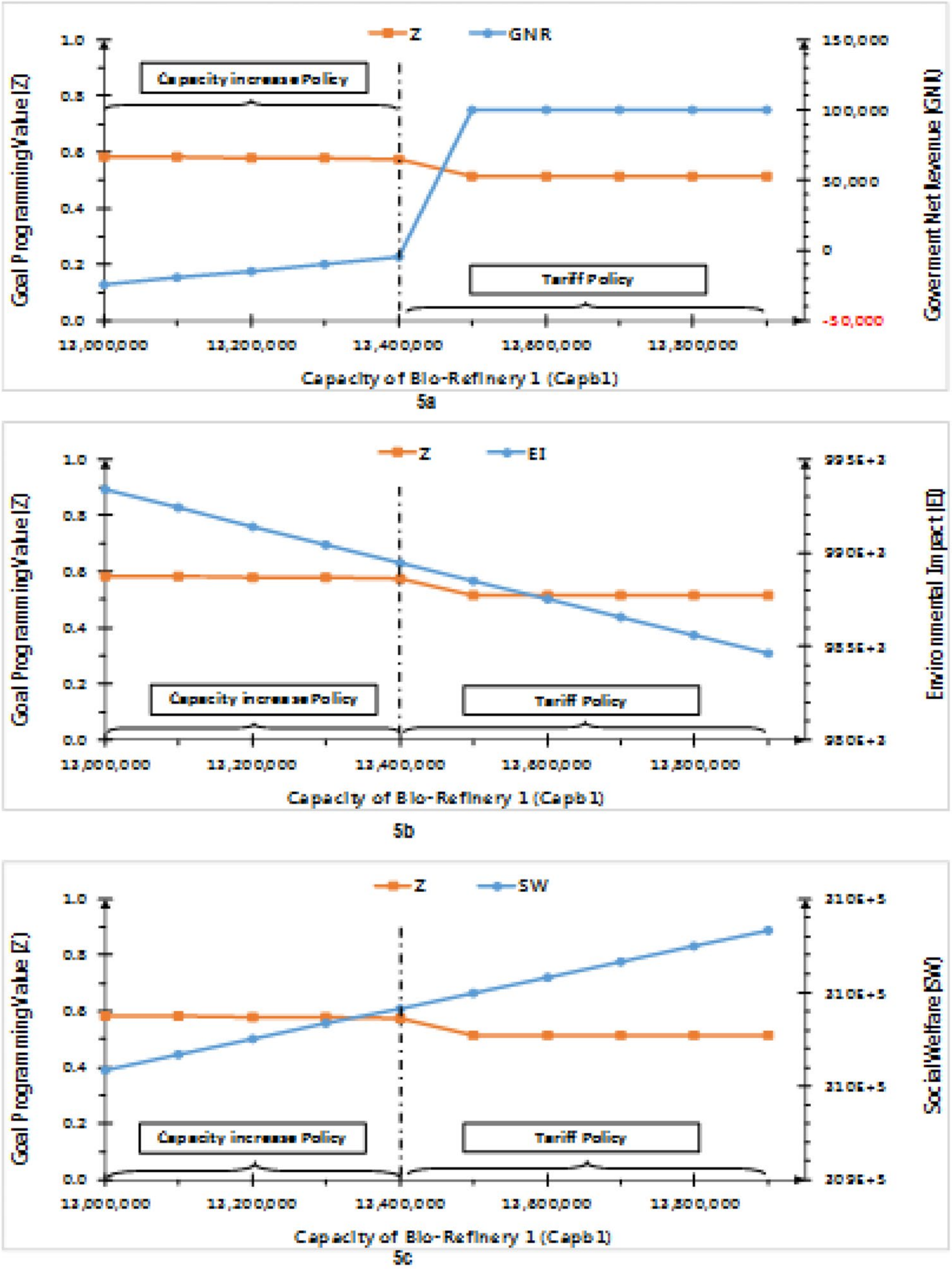

Fig. 5 The sensitivity of the optimal value of the government objective functions according to different amounts of cap_{b1}

8 Conclusion

In this paper, a competition between bio and oil refineries is considered under government policies. In the proposed game theory framework, the government plays a significant role as a leader, and refineries are considered as followers. Moreover, the government implements tariff and investment policies as incentive schemes for refineries. As an optimization model, a bi-level multi-objective mixed-integer nonlinear programming model is presented herein. In our model, the government, as a leader, attempts to achieve sustainability factors such as financial, environmental, and social aspects. For solving the model, the revised MCGP approach is applied, which considers the importance of objectives.

Importantly, our findings have been considered in light of certain unavoidable methodological limitations. We accomplished a case study to confirm the validity of the model. The lack of reliable data has been considered a methodological limitation that caused the model to be studied in a small size to maintain logical relationships between model constraints and achieve an acceptable result. Also, due to the lack of articles that considered the competition of bio and oil fuel, writing further articles may become more representative for the government decisions about the intervention policies on fuel production and consumption for reaching sustainability factors.

It is challenging to encourage refineries to produce fuels with fewer pollutants in a competitive market. It is found that appropriate budget allocation and the optimal quantification of a tariff, as well as investment policies by the government, will encourage refineries to produce fuels with fewer pollutants and provide a high level of social welfare. Therefore, the government plays an extraordinary role in the energy sector to reduce pollution and reach a high level of social welfare.

The multiplicity of goals in community policymaking makes the government, and decision-makers, consider the importance of relevant objectives in achieving sustainability goals such as economic, environmental, and social goals. Considering the importance of each goal, the revised MCGP model, demonstrates a useful performance.

For future studies, there are several possible developments. The first one is developing the mathematical model of refineries by considering supply, production, and distribution factors as three echelons for giving the GSC model of refineries. The second one is considering the competition between two GSCs under government leadership. The third one is finding the equilibrium price of the biofuel by considering other game theory approaches. Applying uncertainty conditions in our model as a fourth development can be interesting. Hydrogen has the potential to contribute to greenhouse gas reduction goals and support a cleaner, more sustainable energy future.

Incorporating hydrogen into the debate about the future of transportation allows for a more comprehensive assessment of potential pathways to a low-carbon and sustainable energy future that requires supportive government policies and investments that could considered as the fifth innovation. At last, development as a heuristic method can be considered useful for a solution approach.

Funding The authors declare that no funds, grants, or other support were received during the preparation of this manuscript.

Data availability Due to the nature of this research, data is available within the text.

Code availability Not applicable.

Declarations

Conflicts of interest/Competing interests The authors have no competing interests to declare that are relevant to the content of this article.

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