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Estimating the Impact of Household Energy Consumption Reduction on Iran's Energy System: A non-linear Programming Optimization Approach

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ABSTRACT

Energy intensity is a critical aspect of Iran's energy system, as the country ranks among the most energy-intensive nations globally, primarily due to high household energy consumption. This article presents a non-linear model exploring three scenarios for reducing household energy demand. It aims to achieve a balanced energy production-consumption ratio while maximizing profit from various reduction strategies. The first scenario involves reallocating a percentage of reduced household energy consumption to lower energy demand in the industrial sector, generating value-added profits. The second scenario focuses on channeling all benefits from household energy savings toward energy exports, thus yielding profits from that source. The third scenario looks at how reduced energy consumption can decrease supply and lower associated costs. Additionally, a combination of these scenarios was modeled. Results show that a 25% reduction in household energy consumption from 2024 to 2034 can eliminate energy imbalances. Allocating 5% of this reduction to the industrial sector could generate profits of approximately 164.18 billion USD. Importantly, the findings indicate that greater emphasis on the first scenario leads to higher profits, with the optimal outcome achieved through its implementation.

Keywords

Household energy demand;
Industrial sector;
GDP;
Energy export;
Energy supply costs;
Modeling;
Net profit Maximization.

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1. Introduction

Iran's vast land size, rugged terrain, and semi-arid climate. Iran is ranked 17th in the world with 79 million people, and in 35 years, its population is expected to climb to 92 million. Policy makers face issues as a result of the quick rise in energy demand brought on by rapid urbanization. Given Iran's large reserves, which include 10% of global oil reserves and 17% of known gas resources [1], energy security is highlighted as being essential for meeting sustainable energy demand. However, due to concerns about depleting resources, economic expansion, and rising living standards, Iran has encountered difficulties over the past three decades in efficiently utilizing its energy resources. Reducing environmental pollution, increasing energy security, preserving natural resources, and cutting industrial costs are all associated with decreasing energy intensity. The goal of improving energy efficiency is to raise energy intensity in both developed and developing nations [2]. The main answers include reducing carbon emissions, severing the link between economic expansion and energy use, and mitigating global warming. Nevertheless, Iran's economy has not become less energy-intensive, in contrast to the worldwide trend [3]. Rather, as shown by a faster growth rate in final energy consumption when compared to economic growth between 1967 and 2014, it consumes more energy with each unit of economic growth. Interestingly, Iran's energy consumption intensity was roughly 2.2 kWh/ USD [4], which is four times higher than the average for the world (see Figure 1).

The high energy consumption intensity in Iran has led to an imbalance between energy production and

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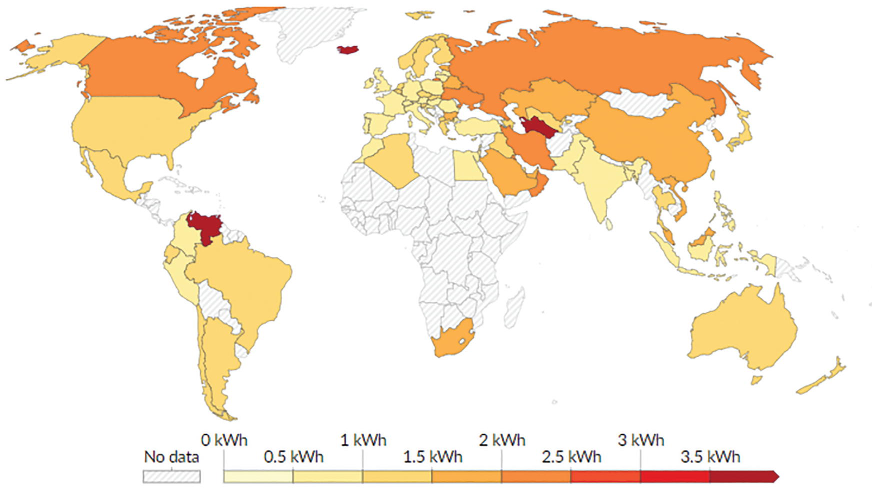

Figure 1: Variations of Energy Intensity in Iran and world in 2020 kWh/ USD [5].

consumption. Therefore, this has resulted in a reduction in power generation, particularly electricity production. The power business faces considerable financial risks as a result of power outages, which lower sales revenue because of a drop in electricity sales and raise troubleshooting expenses [6]. The fast rise in domestic electricity consumption and inefficient electricity use are the main concerns of Iranian energy officials. Iran's per capita power consumption has tripled over the past 20 years (1990–2010), growing at an average rate of 7.9%, exceeding the global average of 3.3% [7]. Worldwide, the household sector accounts for a large portion of electricity consumption; in Iran, in particular, it is the main end-user, accounting for 33.2% of total electricity and 35% of total energy consumption which makes it the highest compared to other sectors [8]. Given the significance of energy for human development, a study on household energy consumption reduction is warranted in this context. In any economy, the energy demands of other sectors—such as industrial, agricultural, and transportation—are better captured than those of the household sector because of factors like centralized ownership, self-interest, and higher levels of regulation and documentation. In contrast, the residential sector is less well defined [9].

This excessive energy consumption in the household sector has led to an imbalance between energy production and consumption in Iran. The primary reason for this energy consumption-production imbalance is attributed to the increasing future energy consumption in the household sector, leading to the shutdown of large energy-intensive industries in Iran. As depicted in Figure 2, this energy imbalance has escalated over time, necessitating considerations for methods to reduce this gap.

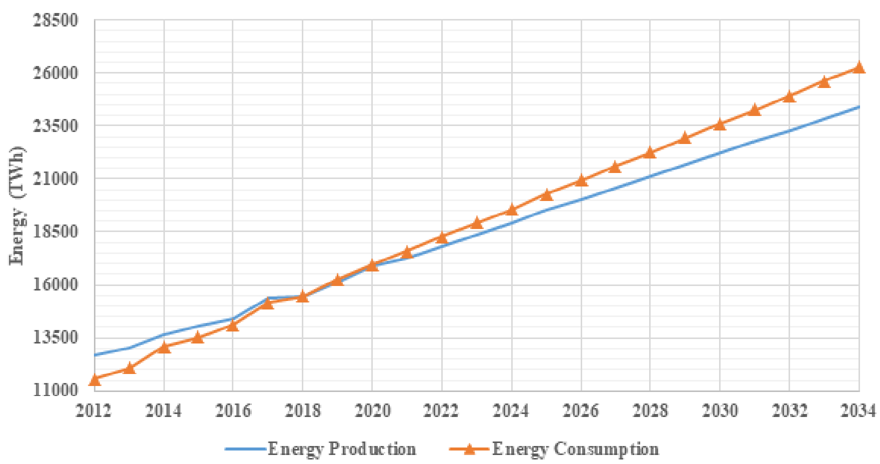

Figure 2: Gap between energy consumption-production in Iran over 2012-2034 [8].

In the years before 2018, due to production capacity, the energy supply was considered to cover the energy demand, in addition to some energy being exported. However, after 2018, due to the increase in energy demand, the energy supply did not meet the increasing energy demand, and in order to meet the energy demand, the domestic sector had to shut down many industries, and there would be no capacity left for energy exports, and the gap between energy supply and demand would also increase over time.

The main focus of this article is to present scenarios for managing energy consumption reduction in line with the allocation of freed financial resources in sectors such as industries, energy exports, or reducing energy supply consumption costs.

In this article, following a review of the literature, a methodology based on nonlinear mathematical programming will be presented, in which three scenarios for increasing GDP in the industrial sector, increasing income from exports of energy liberated resources, and reducing energy supply costs due to a 30% reduction in energy consumption in the household sector are considered. 25% of this energy consumption reduction will be allocated to addressing energy imbalances (Figure 3), and 5% will be examined within the mentioned scenarios in the time interval of 2024-2034.

In this article, three potential scenarios for achieving a 5% reduction in energy consumption in Iran's residential sector (beyond the existing 25% reduction needed to eliminate the imbalance between energy production and consumption) are considered. In the first scenario, it is assumed that the entire reduction in energy consumption is redirected to the industrial sector to generate added value from increased production. Consequently, the entire 5% reduction in energy consumption is treated as an input to the industry, with its output measured in terms of reduced energy intensity and increased production, effectively transferring energy from the non-productive to the productive sector.

In the second scenario, it is assumed that the 5% reduction in energy consumption frees up capacity for energy exports to neighboring countries, with benefits calculated based on international energy prices. The third scenario posits that this 5% reduction in energy consumption leads to a corresponding 5% decrease in energy demand, resulting in a reduced energy supply, which is calculated using the model presented in Figure 5 and the equations provided in the article.

Lastly, a combined scenario is also considered to account for the interactions between the scenarios, distributing the impact of the 5% reduction in residential energy consumption across the three scenarios with varying weights. It is worth noting that the cumulative economic benefit (measured in USD) is used to compare the results of the proposed scenarios.

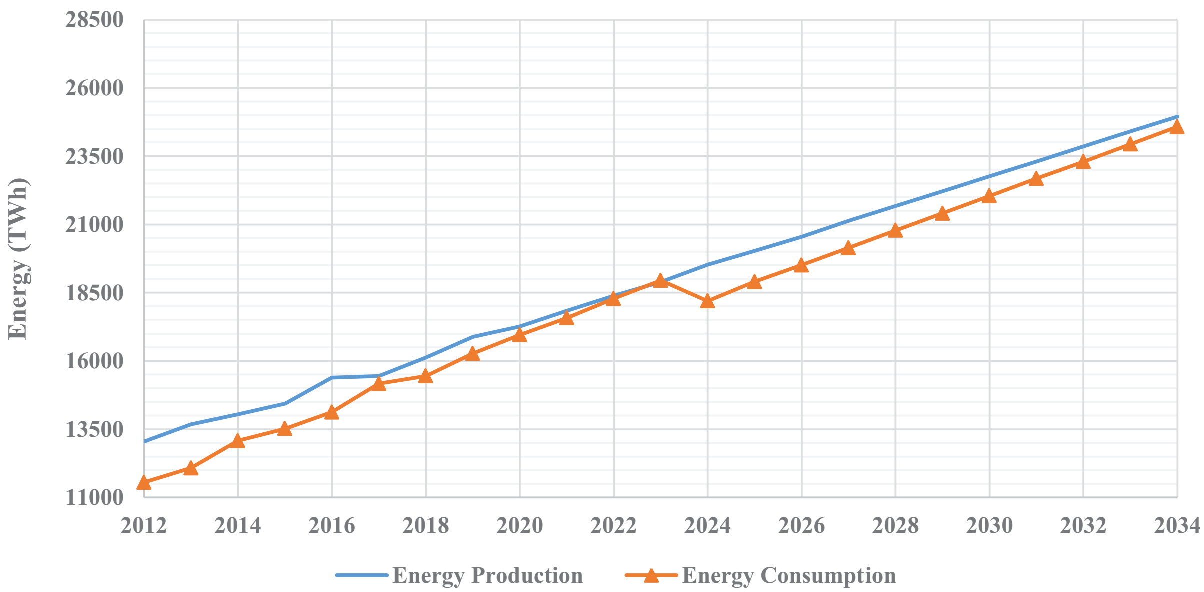

Figure 3: The elimination of energy imbalance through a 25% reduction in energy consumption in the household sector over the time span of 2024-2034.

2. Literature review

In many articles, the importance of energy intensity has been highlighted, and various factors influencing it have been addressed. However, in most of them, the significance of reducing energy intensity in the household sector and transferring the effects of this reduction to other economic sectors has not been mentioned. Sadorsky considered the intensity of energy for 75 countries in relation to development, taking into account industrialization, urbanization, and income [10]. He estimated the model using the panel data method and proved a positive correlation between urbanization and industrialization with energy intensity, and a negative correlation between energy intensity and income [10]. Huang et al. in an article, for the first time, employed a combination of coverage analysis approaches and spatial panel techniques to investigate changes in energy intensity in China from 2000 to 2014 [11]. The results indicated that technological advancements play a significant role in reducing energy intensity in China. The pace of industrialization is also responsible for increasing energy intensity in China, while raising energy prices leads to a decrease in energy intensity. Additionally, there is clear evidence that these factors partially influence energy intensity through spatial spillover effects [11]. Yu, in a research titled "The influential factors of China's regional energy intensity and its spatial linkages: 1988-2007" stated that using spatial panel data models to investigate from 1988 to 2007, per capita gross domestic product, transportation infrastructure, market size, and the influx of science and technology significantly reduce energy intensity [12]. The proportion of heavy industries to total industries and the ratio of coal consumption to total energy consumption greatly increase energy intensity. However, the coefficient of exports to gross domestic product is not substantial. Furthermore, per capita gross domestic product, transportation infrastructure, market size, and scientific and technological advancement, which are subject to convergence effects, are controlled for spatial effects [12]. Farajzadeh et al. [13] used a basic wavelet neural network to investigate the influential factors on energy intensity and its components, namely efficiency and structural changes. According to the findings, there exists a non-linear relationship between energy intensity indicators and income; however, there is no significant relationship between trade and energy prices. Additionally, these researchers found that urbanization has a significant effect on reducing energy intensity [13]. In these articles, the analysis has been focused on examining the consumption of energy intensity, with no mention made of investigating the household sector, the reduction in the intensity of this quantity in this sector, and the sources liberated due to this reduction. Most models of energy demand have neglected the evidence for a trend change in energy intensity, usually assuming a constant elasticity of energy demand to income and a monotonic link between energy consumption and the level of economic activity. Non-monotonic functions of income have been used in other articles instead of monotonic ones (such log-linear functions). Indonesia aims for Net Zero Emissions (NZE) by 2060, using a least-cost optimization method for power plants fueled by both fossil and non-renewable sources. The study indicates that optimal NZE conditions could be reached by 2075, primarily through solar energy, while predicting a 28% increase in electricity demand by 2100 compared to a Business as Usual scenario [14]. Achieving global climate targets from the Paris Agreement poses significant challenges, particularly in sectors with unavoidable emissions, termed Hard-to-abate emissions. In Austria, a comprehensive analysis of CO_2 point sources and their projected development reveals that by 2050, industry is expected to emit around 4 million tons of unavoidable CO_2 annually, necessitating long-term storage and highlighting the role of Carbon Capture and Storage (CCS) and Carbon Capture and Utilization (CCU). Additionally, negative emissions will be crucial for meeting climate goals, and biogenic CO_2 could be utilized as feedstock in the chemical industry [15].

In another category of articles that focused on energy consumption in the household sector, environmental impacts have been predominantly emphasized. Although economic parameters have been incorporated into their models, the economic impacts of energy consumption in the household sector have not been observed on other energy-consuming sectors therein. Druckman and Jackson [16] assert that the level of greenhouse gas (GHG) emissions correlates with household energy consumption. Consequently, altering household behavior is imperative to mitigate energy consumption-related issues and reduce the climate footprint. Waste management emerges as a critical focus area in environmental policy for curtailing GHG [17]. The intensity of greenhouse gas emissions differs among various energy sources. For instance, utilizing natural gas instead of coal in power plants is thought to result in lower greenhouse gas emissions and less harmful air pollution [18]. A study in

Hungary analyzes factors influencing household energy consumption using spatial econometric models, revealing that rising energy prices lead to significant reductions in consumption, although distinguishing specific consumer groups remains challenging. Weather conditions play a critical role, and findings highlight issues with outdated housing and low energy awareness among households, particularly prior to the energy crisis. The research underscores the importance of geography, suggesting that targeted, spatially concentrated interventions are necessary for effective energy efficiency improvements, especially in regions with high per capita gas consumption in Hungary [19]. A paper examines three case studies demonstrating how Smart Local Energy Systems (SLES) can economically achieve net zero carbon emissions by utilizing waste heat from various industries across England. The studies, based on the GreenSCIES model, showcase a fifth generation district heat network in London that integrates waste heat from a data center, alongside additional networks utilizing heat from a foundry and glassworks. These projects highlight the potential of integrating local waste heat sources into heat networks while emphasizing the need for collaboration among researchers, local governments, and industry to meet carbon reduction targets [20]. Another paper presents a planning approach for low-carbon heat supply in future district heating systems for German cities with existing networks, emphasizing the integration of industrial waste heat and the uncertainties surrounding future sources and biomass restrictions. It demonstrates how to estimate energy demand around a heating network using spatial data and generate a corresponding load profile. Additionally, the study assesses the suitability of local heat sources for integration into the heating network [21].

Energy conservation and changing home behavior are two essential approaches for lowering GHG emissions, according to Oladokun and Odesola [22]. Research from a variety of lifestyles shows that home behavior has a direct impact on energy use. For example, in 1998, running a dishwasher accounted for 21% and 51% of the energy used by homes in the UK and Sweden, respectively [23]. According to Farajzadeh and Nematollahi's [24] study on energy intensity in Iran, the residential sector is responsible for roughly 20% of the country's overall energy consumption and 33% of its CO_2 emissions. Thus, the purpose of this overview is to collect information intended to reduce home energy use and related CO_2 emissions in Iran. The results of this review have a big impact on research projects that try to lower household CO_2 emissions. Comprehending the prevailing patterns of consumption in the household sector is expected to aid policymakers in formulating strategies targeted at endorsing sustainable energy supply and consumption in the nation [25]. In an article by Godarzi et al., a System Dynamics-based model was developed to estimate the greenhouse gas emissions intensity index in Iran [26]. The study focused on examining the environmental benefits of optimizing energy consumption considering the penetration of renewable technologies in the electricity supply system [26].

3. Methodology

In this paper, an economic assessment of the benefits derived from reducing energy consumption in the residential sector has been conducted using a nonlinear programming model based on a cost model. The objective function of the model aims to maximize these benefits. While various articles have examined different aspects of energy consumption reduction and its environmental impacts, the primary innovation of this paper lies in presenting a comprehensive model for estimating the economic benefits resulting from reduced energy consumption in the residential sector, aiming to encompass all possible aspects in this regard. The model presented explores comprehensive benefits arising from reduced energy consumption in the residential sector across three scenarios. In the second phase, it is determined which scenario yields greater benefits. In the first scenario, the focus is on the impact of reducing energy consumption in the industrial sector. In Iran, one of the fundamental challenges in the industrial sector is reduced input due to energy supply for the residential sector, leading to electricity shortages in summer and natural gas shortages in winter. In the second scenario, the study examines benefits from exporting energy carriers resulting from reduced energy consumption in the residential sector, where the variables of residential energy reduction and export energy prices are influential. The third scenario employs a cost model to estimate benefits from reduced energy supply resulting from decreased residential energy consumption.

In the model presented in this paper, multiple parameters have been considered, and the manner in which these parameters are incorporated and the results extractable from the model are illustrated in the figure below.

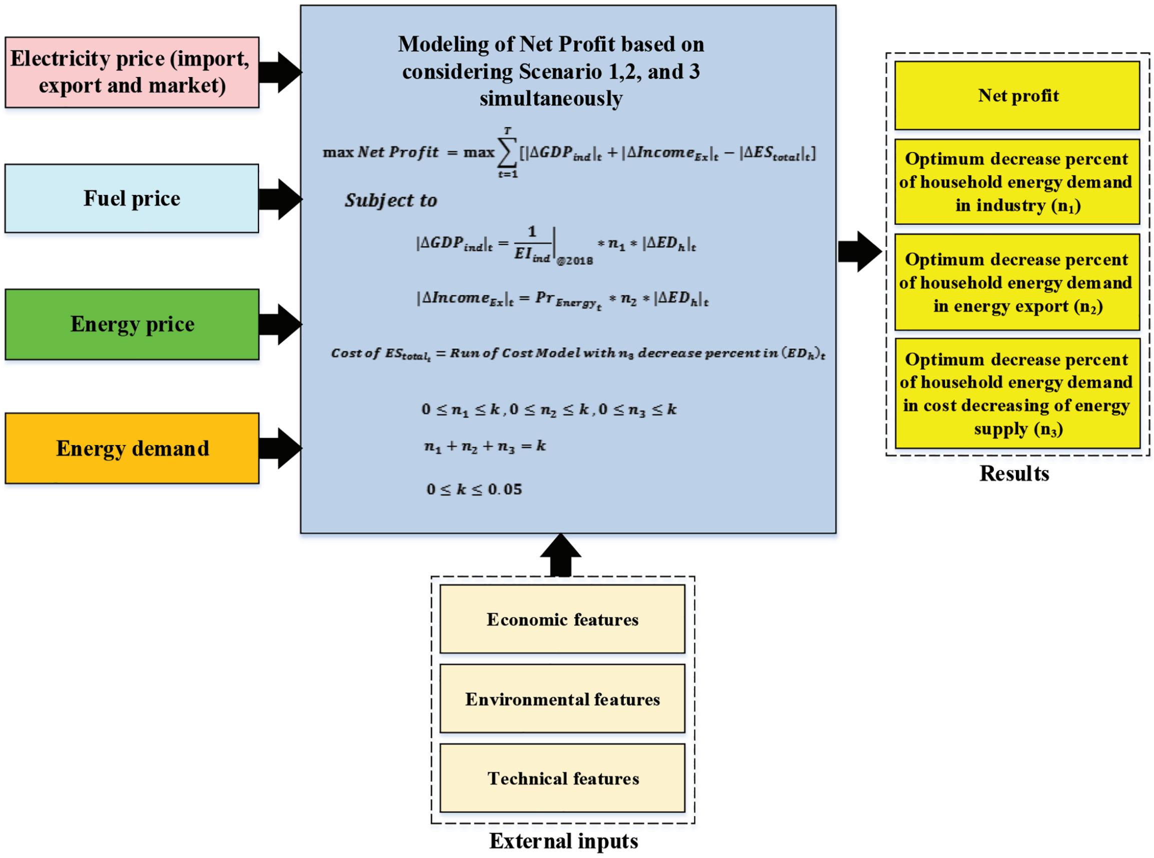

Figure 4: Schematic of inputs and outputs of model based on developed model in this article.

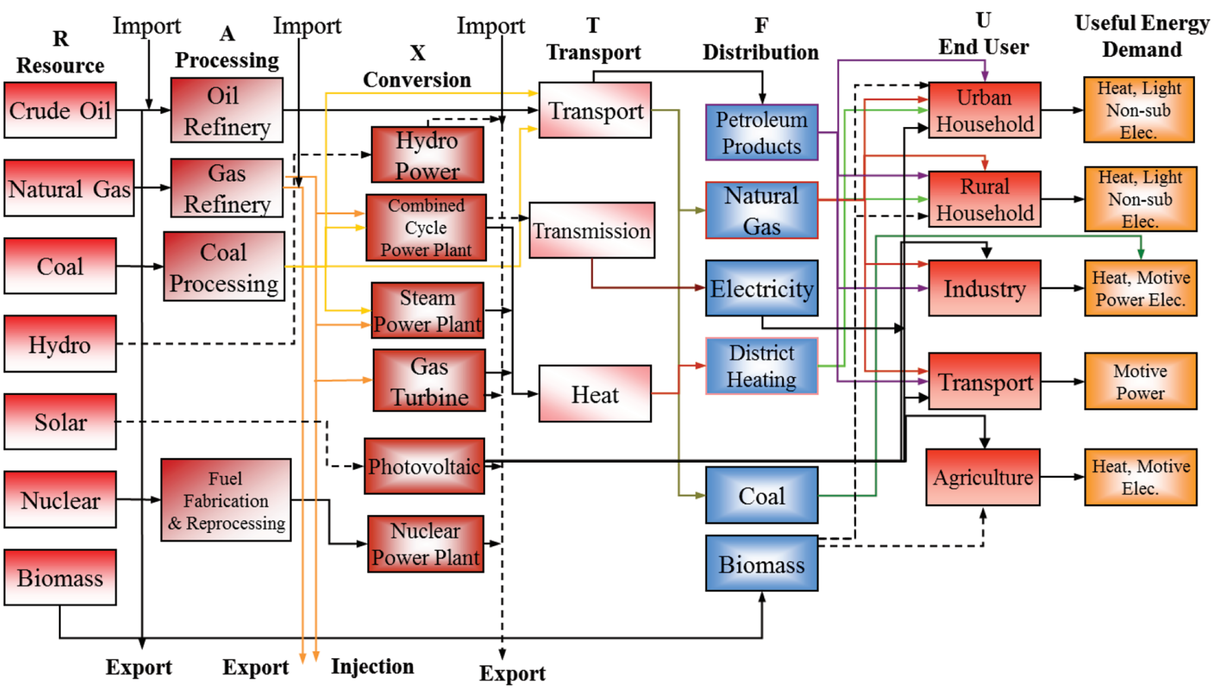

Figure 5: Iran's energy supply and demand side reference energy system [31].

In contrast to traditional energy software models like LEAP, the model presented in this research enables the explicit construction of energy equations that may effectively reflect complicated energy systems and desired techniques. This model has been modified to fully handle the behavior of primary energy sources, in contrast to black box techniques. Like bottom-up models such as MARKAL, TIMES, and MESSAGE, the study shows the whole energy flow across several energy tiers using a Reference Energy System (RES). In the MARKAL [27], TIMES [28], and MESSAGE [29] models, the equations are predefined, and there is no flexibility to modify them. However, in our proposed model, the equations are formulated within the framework of a mathematical programming model, enabling them to accommodate the three scenarios under investigation. This capability is not feasible in the aforementioned models.

In the present paper, a mathematical programming model is used, which can be enhanced using the EnergyPLAN model. Although other models such as MARKAL, TIMES, and MESSAGE are also discussed, the greatest potential for model enhancement exists with the EnergyPLAN model [30].

A RES tailored to Iran's system is depicted in Figure 5, which provides a framework for demonstrating the integration of various technologies and their interactions under the auspices of mass and energy conservation [31].

This paper endeavors to provide a precise assessment of the benefits derived from reducing energy consumption in the residential sector from three perspectives: energy supply, demand, and exports. By simultaneously implementing the model across three scenarios, the results are presented.

The main parameters and variables are presented in Table 1.

Table 1: Parameters and variables of this article.

Parameters		**Variables**	
Pe.t	Electricity prices in USD/MBOE	*Qi.t*	Productions in MBOE
Pif	Fixed Operation and Maintenance (O&M) costs in USD/MBOE	*Ci.t*	Energy technology capacities increment in MBOE/h
Piv	Variable O&M costs in USD/MBOE	*Qim.t*	Amount of import energy in MBOE
EI	Energy Intensity in MBOE/USD (@2018 PPP)	*Qex.t*	Amount of export energy in MBOE
ci	Capital costs in USD/MBOE	ES	Energy Supply in MBOE
GDP	Gross domestic production	*ΔSt*	Net output energy of storage system in MBOE
Pr	Energy Price in USD/BOE	*CSt*	Storage system capacity in MBOE/h
Ch	Energy production technology history capacities in MBOE/h	Income	Income of energy export in USD
CSh	Storage system history capacity in MBOE/h		
φi	Maximum capacities in MW		
hi	Plant factors in %	*Subscripts*	
ηi	Energy production technology efficiency in %	*i*	Energy production technology number
Pfi	Fuel costs in USD/MWh	*t*	Time
ηi	Power plants efficiency in %	*im*	Import
Pim.t	Price of import electricity in USD/MBOE	*ex*	Export
Pex.t	Price of export electricity in USD/MBOE	*ind*	Industry
r	Annual real interest rate in %	*h*	Household
j	Nominal interest rate in %		
f	Annual inflation rate in %		
n	Total number of energy production technology		
ED	Energy demand in MBOE		
EL	Energy loss of transmission level in %		
by	Base year		

(Table 1 continued)

PLi	Power plant technology life
PLs	Storage energy system life
l	Load zone
n_1	The extent to which reducing residential energy consumption contributes to increasing the GDP of the industrial sector
n_2	The extent to which the reduction in residential energy consumption contributes to energy exports in %
n_3	The extent to which the reduction in residential energy consumption contributes to decreasing the overall energy supply in %
k (= 0.05)	The extent of reduction in energy consumption by the residential sector in %

In this article, we optimize the total benefits derived from a 5% reduction in energy consumption in the residential sector using a nonlinear mathematical model developed in MATLAB software. Initially, Eq. 1 to Eq. 10 are detailed to model the triple scenarios, followed by the application of Eq. 11 to Eq. 25 in the optimization toolbox of the software. This section focuses on explaining the employed equations and delving into their specifics.

Scenario 1:

$$EI_{ind} = \frac{ED_{ind}}{GDP_{ind}} \Rightarrow \Delta GDP_{ind} = \frac{1}{EI_{ind}}\bigg|_{@2018} * \Delta ED_{ind} \quad (1)$$

$$ED_{total} = ED_h + ED_{ind} + ED_{agriculture} + ED_{transport} \quad (2)$$

We supposed that n_1 percent of energy demand decrease in household only causes to decrease of energy demand in industry section. So,

$$\Delta ED_{agriculture} = \Delta ED_{transport} = \Delta ED_{total} = 0 \Rightarrow \Delta ED_h = -\Delta ED_{ind} \quad (3)$$

$$|\Delta GDP_{ind}| = \frac{1}{EI_{ind}}\bigg|_{@2018} * |\Delta ED_h| \quad (4)$$

Scenario 2: We supposed that n_2 percent of energy demand decrease in household only causes to releasing of financial resources in energy export. So,

$$|\Delta ED_{ind}| = 0 \quad (5)$$

$$|\Delta Income_{Ex}| = Pr_{Energy} * |\Delta ED_h| \quad (6)$$

Scenario 3: We supposed that n_3 percent of energy demand decrease in household only causes to decrease of energy supplying and finally we see a decrease in cost of this energy supplying. So,

$$ES_{total} = ED_{total} + E_{export} - E_{import} + E_{loss} \quad (7)$$

$$\Delta ED_{ind} = \Delta ED_{transport} = \Delta ED_{agriculture} = 0 \Rightarrow \Delta ED_{total} = \Delta ED_h \quad (8)$$

$$|\Delta ES_{total}| = |\Delta ED_{total}| = |\Delta ED_h| \quad (9)$$

$$Cost\,of\,\, ES_{total} = Run\,of\,Cost\,Model\,with\,n_3\ decrease\,percent\,in\,ED_h \quad (10)$$

Cost Model (Eq. 11 to Eq. 17):

$$\min Z = \min \sum_{i=1}^{n}\sum_{t=1}^{T}\left[\left(\frac{Q_{i.t}P_i^v}{(1+r)^t} + \frac{C_{i.t}P_i^f}{(1+r)^t} + C_{i.t}c_i + \frac{Q_{i.t}e_i\lambda_i k}{(1+r)^t} + \frac{Q_{i.t}Pf_{i.t}}{\eta_i(1+r)^t}\right)\right] + \sum_{t=1}^{T}\frac{[P_{im.t}Q_{im.t} - P_{ex.t}Q_{ex.t}]}{(1+r)^t} \quad (11)$$

$$s.t.\left[\sum_{i=1}^{n} Q_{i.t} + \Delta S_t + (Q_{im.t} - Q_{ex.t})\right][1-EL] \geq ED_t - ED_h \quad (12)$$

$$\sum_{t=1}^{T} C_{i.t} + C_i^h \leq \varphi_i \quad (13)$$

$$\frac{Q_{i.t}}{\Delta l} \leq h_i C_{i.t} + h_i \sum_{\theta=by-(PL_i-t)}^{by} C_{i.\theta}^h \quad (14)$$

$$\frac{\Delta S_t}{\Delta l} \le h_i \times CS_t + h_i \times \sum\nolimits_{\theta=by-(PL_s-t)}^{by} CS_\theta^h \quad (15)$$

$$0.0125\sum\nolimits_{i=1}^{n} Q_{i.t} \le Q_{im.t} \le 0.05\sum\nolimits_{i=1}^{n} Q_{i.t} \quad (16)$$

$$0.025\sum\nolimits_{i=1}^{n} Q_{i.t} \le Q_{ex.t} \le 0.1\sum\nolimits_{i=1}^{n} Q_{i.t} \quad (17)$$

The fixed O&M costs and variable costs are discounted annually at rate r in Eq. 11. The rate of discount is estimated as follows:

$$r = \frac{j-f}{1+f} \quad (18)$$

The nominal interest rate (j) and the annual inflation rate (f), which had respective values of 9.5% and 19% in May 2018, are linked to the real annual interest rate (r) with value of 7.9% [32].

Cost Model had been developed by Godarzi et al. in [33]. All variables and parameters were introduced in this article and because of length of this paper, we do not represent details of this model.

It is worth noting that in the MARKAL and LEAP models, equations are developed based on predefined formulas, and there is no capability to add equations that calculate the reduction in energy consumption as a comprehensive model resulting from a 5% decrease in household energy consumption. On the other hand, in the combined scenario, where different weights are assigned to various scenarios, modelling is not feasible in the LEAP and MARKAL models. Therefore, the mentioned modelling has been carried out based on the equations provided in the article and reference [33]

In Cost Model, the market clearing condition, which takes into account net energy imports (imports less exports) and energy distribution losses, guarantees that the total supply from all energy production technology meets the demand in the restrictions mentioned above. The capacity of each energy production technology comprises installed capabilities that are planned for future years as well as historical values.

Furthermore, the installed capacities of energy production technologies multiplied by annual availability factors (plant factors) limit their production. The net energy production of storage systems is restricted by their installed and existing capacities. Crucially, the model also takes import and export restrictions into account.

Finally, we considered *k* percent decrease in household energy demand and distributed this percent on three n_1, n_2, and n_3 percent that mentioned in three states. So, optimization model was developed in bellow form.

$$\max \textit{Net Profit} = \max \sum\nolimits_{t=1}^{T} \left[\left|\Delta GDP_{ind}\right|_t + \left|\Delta Income_{Ex}\right|_t - \left|Cost\, of\, ES_{total}\right|_t \right] \quad (19)$$

$$s.t.\ \left|\Delta GDP_{ind}\right|_t = \left.\frac{1}{EI_{ind}}\right|_{@2018} * n_1 * \left|\Delta ED_h\right|_t \quad (20)$$

$$\left|\Delta Income_{Ex}\right|_t = Pr_{Energy t} * n_2 * \left|\Delta ED_h\right|_t \quad (21)$$

$$Cost\, of\, ES_{total_t} = Run\, of\, Cost\, Model\, with\, n_3\ decrease\, percent\, in \left(ED_h\right)_t \quad (22)$$

$$0 \le n_1 \le k, 0 \le n_2 \le k, 0 \le n_3 \le k \quad (23)$$

$$n_1 + n_2 + n_3 = k \quad (24)$$

$$0 \le k \le 0.05 \quad (25)$$

This paper aims to optimize the benefits derived from reducing energy consumption in the residential sector through the implementation of energy management policies. It considers three scenarios (detailed in the following section) to achieve maximum profitability. The methodology depicted in Figure 7 is employed for this purpose.

4. Scenarios and data

In this article, based on the maximum benefits derived from a 5% reduction in household energy consumption surplus (considered as a 25% reduction to eliminate the energy production-consumption imbalance in the country), three plausible development scenarios have been developed, each pursuing a specific objective. These scenarios are formulated based on profit maximization logic and require data specific to the timeframe of model implementation as outlined in this section.

The base year and scenario implementation period chosen for this paper are 2018 and 2024–2034, respectively. The load modeling parameter (l) and time step are based on the annual value.

The study's scenarios assume steady population and energy consumption growth rates. Energy usage is categorized by demand and influenced by macroeconomic factors such as population size, GDP, and electricity costs. Iran's energy demand forecasts are based on its long-term energy sector development plan [34]. Energy demand in the household sector, which is a key parameter of this model, has been estimated and projected based on the assumptions provided in [35], as illustrated in Figure 6.

4.1. Scenario 1

In this scenario, given the significant role of industry in GDP production, the benefits of a 5% reduction in energy consumption in the residential sector have been concentrated on the industrial sector. One of the main reasons for the high energy intensity in Iran is energy consumption in non-producing sectors such as residential. If this energy consumption is addressed more in the industrial sector, each unit of energy consumed will contribute added value to the country's economic cycle. This action will stabilize overall energy intensity and lead to a reduction. The primary focus in this scenario is on the benefits derived from reducing energy consumption in the industrial sector.

4.2. Scenario 2

In the second scenario, the primary objective is to estimate the benefits of a 5% reduction in energy consumption in the residential sector aimed at freeing up new capacities for energy exports. Essentially, in this scenario, it is assumed that this reduction in energy consumption is allocated to international energy markets, and the benefits derived from it, in terms of foreign exchange, enter the country's economic cycle and production. Consequently, the added value obtained from energy carriers, considering international prices, is introduced into domestic markets.

4.3. Scenario 3

In the third scenario, the aim is to evaluate the impact of a 5% reduction in energy consumption in the residential sector (resulting in a decrease in energy demand) on reducing energy supply. By reducing energy supply, the costs associated with energy flow will decrease, thereby reducing costs related to increasing energy production and supply capacity over time. Therefore, to implement this scenario, a model for energy supply needs to be developed that estimates the reduction in energy supply costs in proportion to the decrease in energy demand.

Rational prediction in price of electricity [36], natural gas, gas oil, kerosene, LPG, and coal which formed energy carriers of household section has been done in [37, 38, 39, 40, 41] and were imported to the model as

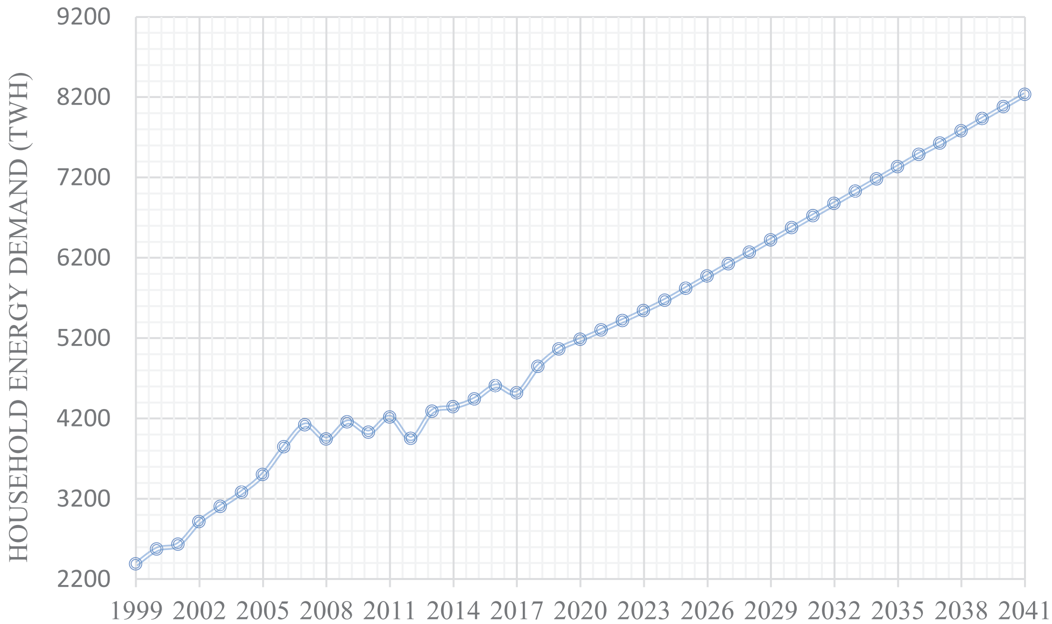

Figure 6: Household energy demand of Iran [35].

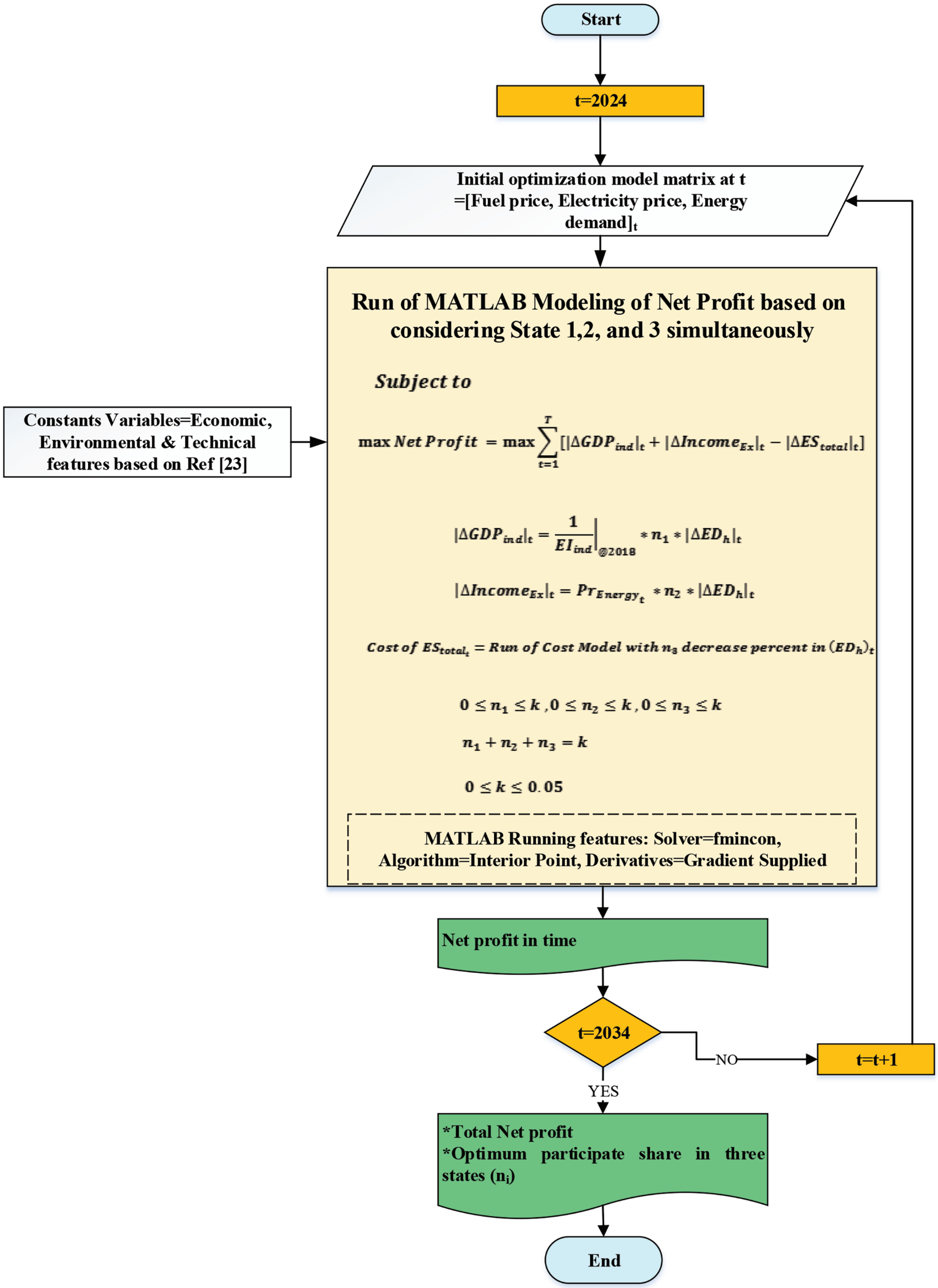

Figure 7: Methodology flowchart of this article.

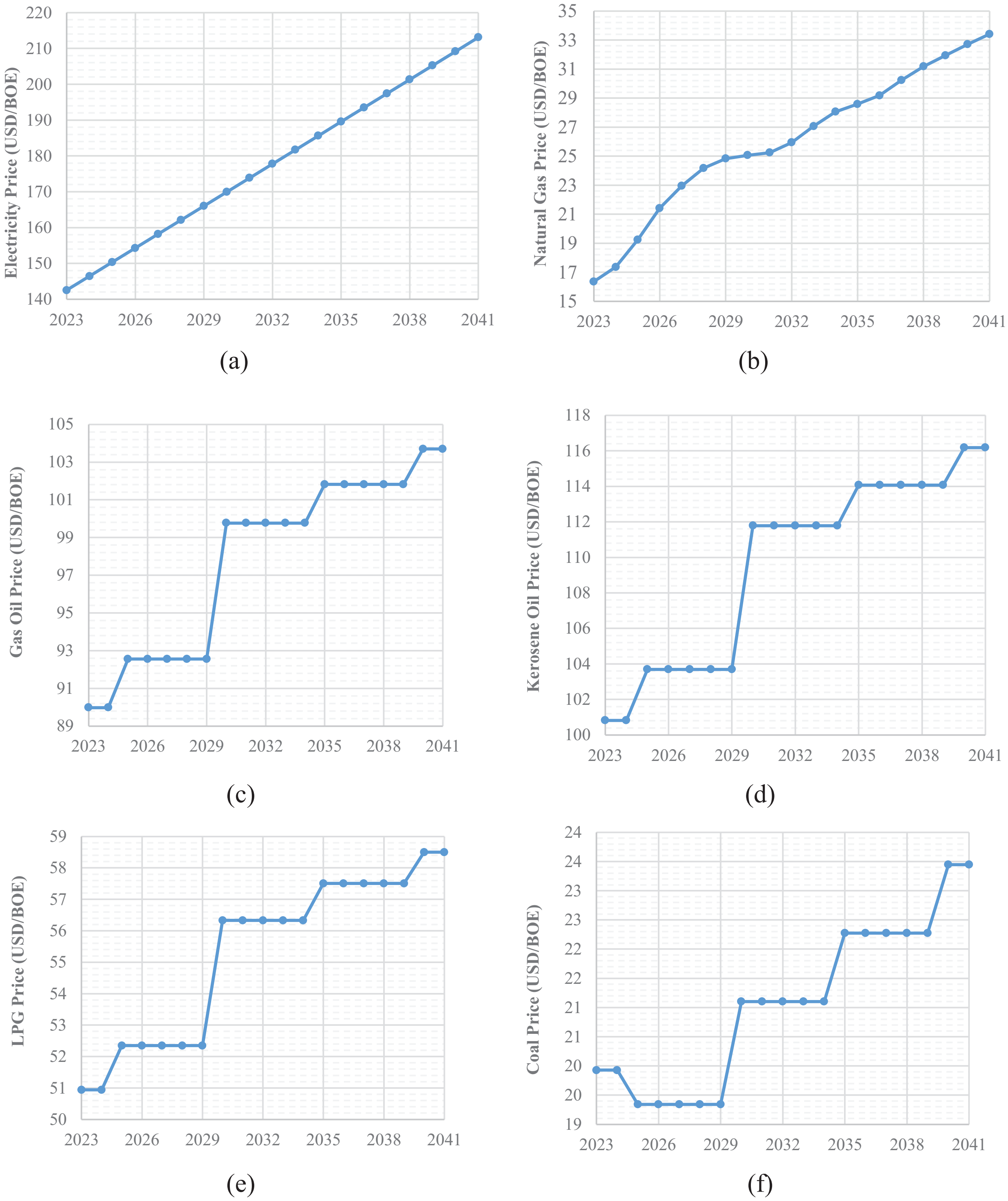

Figure 8: Electricity [36] (a), natural gas (b), gas oil (c), kerosene (d), LPG (e), and coal (f) [37, 38, 39, 40, 41] price change in Iran (export price).

exogenous variable. These prices are shown below in Figure 8.

In this article, an attempt has been made to apply a combination of scenarios concurrently in the model in addition to the three mentioned scenarios, so that a comprehensive view yields precise results from the model execution. However, the weight of scenarios has been determined based on their percentage contribution (n_i) to the model execution.

5. Results and discussion

In this section, the results obtained from executing various scenarios based on the input data mentioned earlier will be presented. Initially, the results of three scenarios will be separately described, followed by the results of executing the model using a combined and concurrent approach. It should be noted that in the combined approach, based on the net benefit obtained, an optimal point will be identified to determine which scenario-oriented policy yields the best outcome.

5.1. Results of Scenario 1

In the first scenario, the impact of reducing household energy consumption on GDP has been examined. The results obtained over the specified timeframe indicate an average annual growth rate of 2.2%, increasing from an accumulated value of 13.33 billion USD in 2024 to 164.18 billion USD in 2034 and this signifies an upward trend over the years in the net profit resulting from the implementation of this scenario (see Figure 9).

In this scenario, as predicted, the profit volume for the period 2024-2034 exceeds 164.18 billion USD, derived from the GDP generated by the industrial sector, which is considered the driving engine of the country's economic development. Furthermore, the profit from implementing this scenario can be utilized to create infrastructure for developing the country's energy supply system, thereby reducing household energy consumption by only 5%. This results in such a substantial profit volume.

5.2. Results of Scenario 2

In the second scenario, the profit from the release of export capacity of energy carriers resulting from a 5% reduction in household energy consumption has been emphasized. Based on the findings within the studied time interval, this scenario exhibits a growth rate of 6%.

As illustrated in the figures below, the cumulative profit from implementing this scenario will increase from 0.8 billion USD in 2024 to 12.41 billion USD in 2034. This profit amount is significantly lower compared to the scenario 1, indicating that utilizing the benefits of a 5% reduction in household energy consumption domestically and within the industrial sector for value-added production is much more valuable than exporting it outside the country's economic cycle and bringing it back as dollars into the economy.

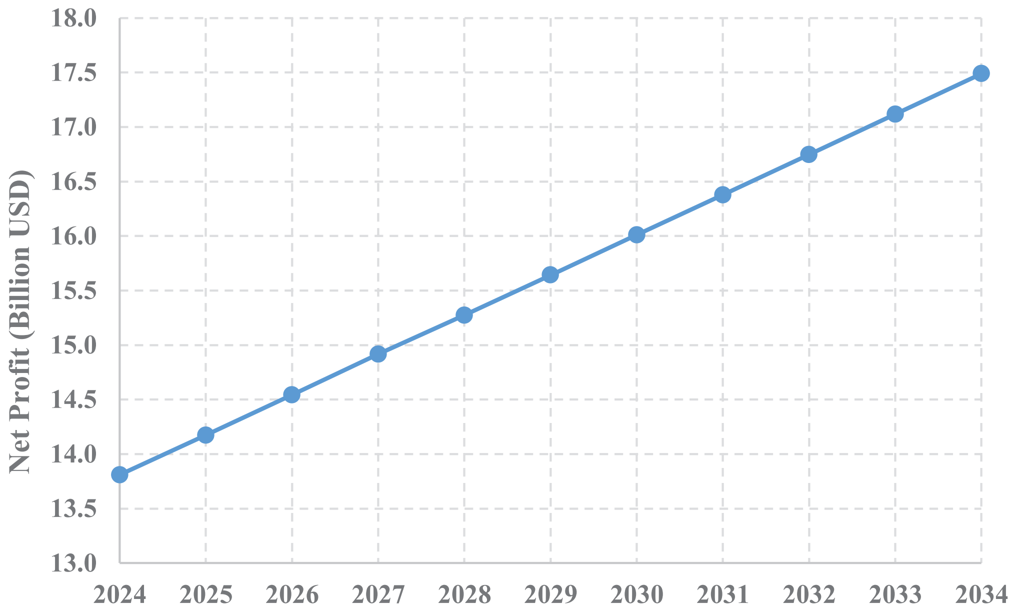

Figure 9: Accumulative net profit in Scenario 1 (Billion USD).

5.3. Results of Scenario 3

In the third scenario, the focus was on the reduction of energy consumption in the household sector, leading to a decrease in energy supply and consequently reducing the country's energy supply system costs. The results indicate that the cumulative profit from implementing this scenario has increased from 1.85 billion USD in 2024 to 24.71 billion USD in 2034, with an average annual growth rate of 3.6%.

The profit generated from implementing this scenario, as depicted in the figure below, is higher than Scenario 2 but still lower than Scenario 1. Therefore, transferring the full benefits of reducing household energy consumption to the industrial sector and generating GDP from it is much more beneficial and impactful than exporting energy carriers and reducing the country's energy supply system costs. For a more comprehensive analysis, we will examine a combination of

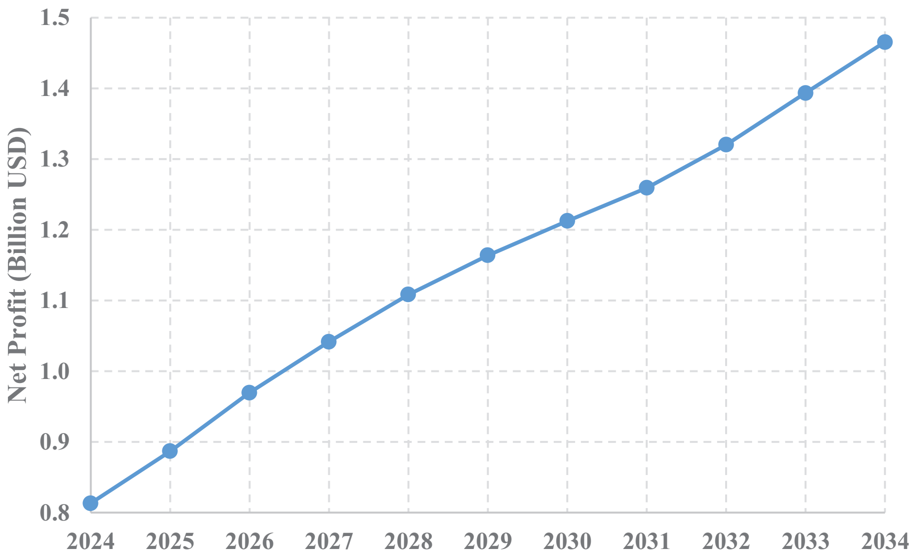

Figure 10: Accumulative net profit in Scenario 2 (Billion USD).

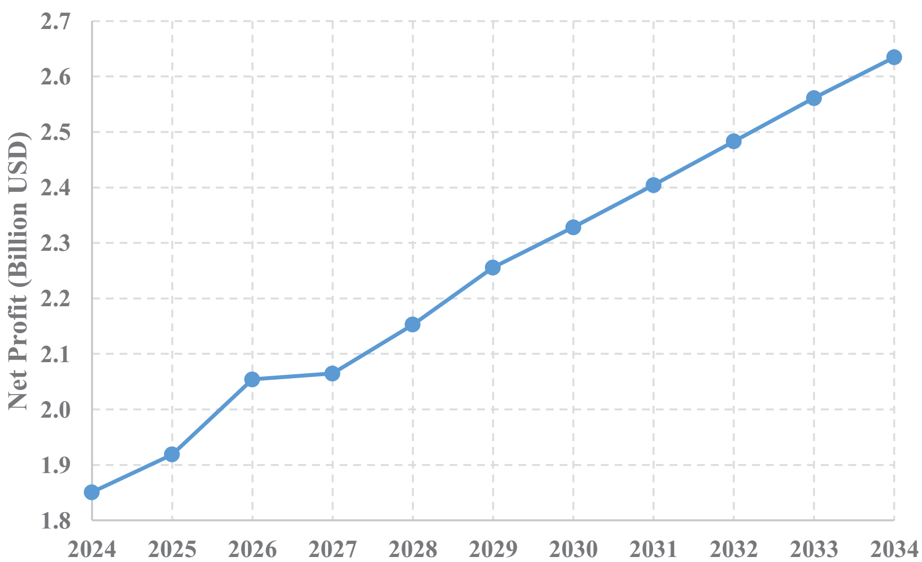

Figure 11: Accumulative net profit in Scenario 3 (Billion USD).

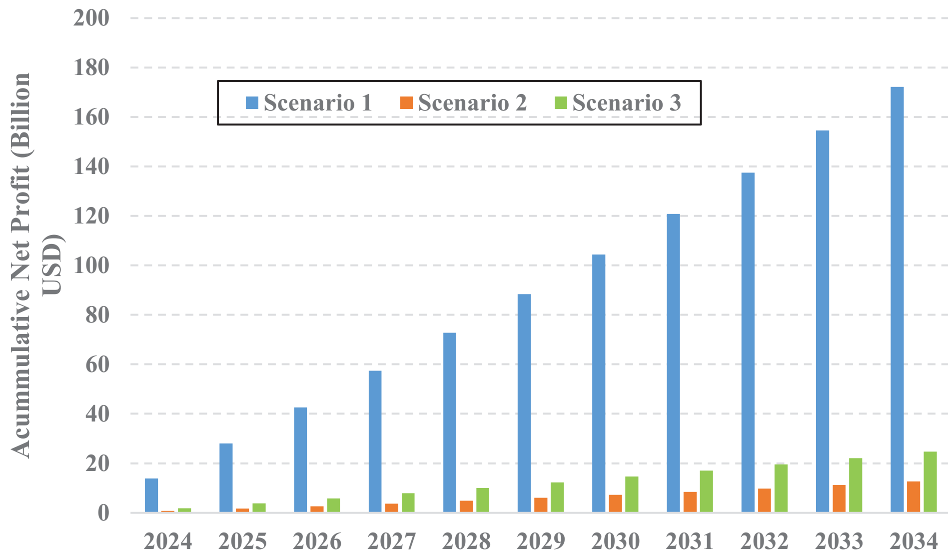

Figure 12: Comparison among the three scenarios in terms of cumulative net profit (Billion USD).

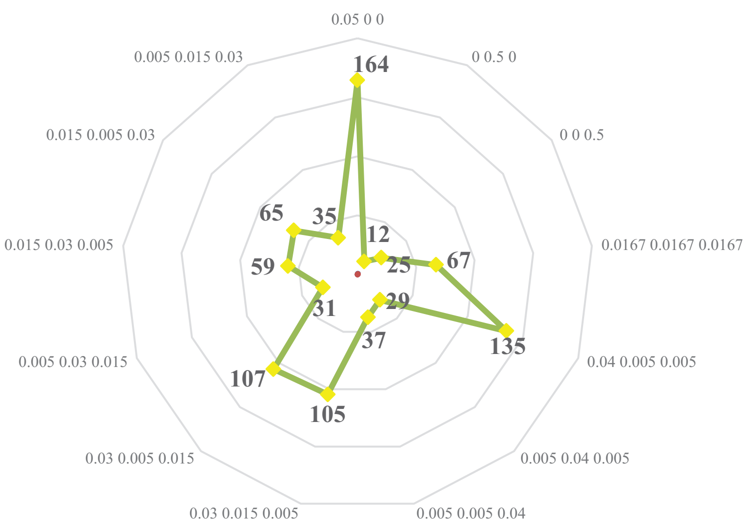

Figure 13: Radar diagram demonstrating the execution of a comprehensive model with varying weights, depicting the influence shares of the factors in triple scenarios (first 10 iterations are shown).

these three scenarios in the next section to extract an optimal comprehensive point.

5.4. Simultaneous Implementation of Scenarios

In previous sections, each scenario has been independently executed, and the results have shown the superiority of Scenario 1. For a more comprehensive investigation, these scenarios have been compared by combining them with different weights representing the influence of their respective factors (with varying values of n_1). The range of variation for each weight is from 0 to 0.5. The obtained results are depicted in a radar chart format as ordered triples (n_1, n_2, n_3) (The initial implementation steps of the model are presented in Figure 13)

Based on the above diagram, the significant impact of the weight of the share benefits derived from reducing energy consumption on increasing industrial GDP production (n_1) is apparent. The higher this weight, the greater the resulting benefits. According to the results, the highest value on the ternary plot (0.5 0 0) is observed at

164 billion USD, and considering the Eq. 25, the values of n_i change accordingly. Reducing the value of n_1 decreases profits, but when this value increases relative to n_2 and n_3, profit levels increase. Therefore, in the best-case scenario, energy policy should prioritize leveraging the benefits derived from a 5% reduction in energy consumption towards increasing industrial production to boost GDP. Secondly, this can also contribute to reducing national energy supply costs. Additionally, energy exports could be considered as a third priority. Given the results and the absence of critical infrastructure, the third scenario requires more precautions to be taken into account.

6. Conclusions

This article highlights the importance of energy intensity in Iran's energy system and the country's ranking among the world's most energy-intensive countries, mostly as a result of high household energy consumption. The paper presents a non-linear model that investigates three scenarios meant to efficiently manage and lower household energy use. The main goal is to rationally reduce household energy usage in order to balance the production and consumption of energy and provide economic results from different reduction tactics. The article talks about the earnings from three different situations:

1. In the first case, the industrial sector's energy demand is reduced through the reduction of domestic energy consumption, which boosts value creation and profitability in this industry.
2. In order to maximize export earnings, the second scenario aims to shift all advantages from lower home energy consumption to energy exports.
3. The third scenario predicts lower energy supply due to lower energy use, which in turn lowers energy supply costs.

Through the integration of various scenarios and a thorough analysis, the study concludes that energy imbalances might be eliminated with a projected 25% reduction in household energy use from 2024 to 2034. Interestingly, it is predicted that in the first scenario, dedicating all 5% of this decrease to the industrial sector alone will result in significant profits totaling 164.18 billion USD. The analysis highlights the relationship between increased investments in the first scenario and increased profitability, designating it as the best course of action out of all the combined possibilities that were examined.

Although the first scenario is proposed as the optimal scenario of this article, its implementation faces certain limitations. One of these limitations is the low capacity of Iran's industries to absorb the input energy resulting from a 5 percent reduction in the residential sector. In fact, many of the country's industries are outdated, and they have been in operation for many years. On the other hand, in the industrial sector, the reduction in energy consumption intensity faces many challenges due to improper management of economic resources in this area. Therefore, there is a possibility of a percentage of this reduction in energy consumption being absorbed in the industrial sector, and achieving 100 percent implementation of the first scenario requires fundamental structural reforms in the industrial sector.

Based on the aforementioned points, the optimal policy for guiding and managing the benefits derived from reducing household energy consumption is directing these benefits towards the industrial sector to increase GDP production in this sector. Given the existing infrastructure and capacities within the country, this approach can effectively optimize the national energy flow

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