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Research article

A DEA model to sustainability improvement of the electricity supply chain in presence dual-role factors and undesirable outputs: A case on the power industry

Mojgan Pouralizadeh*

Department of Applied Mathematics, Lahijan Branch, Islamic Azad University, Lahijan, Iran

* **Correspondence:** Email: pouralizadehmojgan@yahoo.com, pouralizadeh@Liau.ac.ir; Tel: +00989113315783

Abstract: The energy and industrial sectors are the most attractive investment regions for enhancing efficiency in production processes. The power industry is one of the important investment targets for enhancing corporate sustainability. One of the most fundamental problems in the power industry is the control of wasted energy in oil and gas fields and power plant sectors and the power losses management in transmission and distribution lines. The investment to new technology innovation and environmental protection from pollution gases emission in energy and power plant sectors and the power losses management in transmission and distribution lines play an important role in the implementation progress of the power industry. The purpose of this study is to examine the effects of investment to flare gas and greenhouses gases reduction in energy and power plant sections and power losses control by equipping sections to improved engineering systems in transmission and distribution networks of the electricity supply chain. Indeed, the supply chain management needs information related to investment effect to activity level control as handling flare gas in energy sections and reducing harmful substance emissions and greenhouses gases in power plant sectors and harnessing power losses in transmission and distribution networks. The proposed approach evaluates the sustainability and efficiency of an electricity supply chain by a radial model in the presence of two categories of inputs under natural and managerial disposability, dual-role factors and undesirable produces. A real case on the Iran power industry is presented to demonstrate the applicability and practicability of the proposed method. Moreover, to demonstrate the capability of the proposed approach a supply chain identified by oil and gas companies, power plants, transmissions companies, dispatching companies and final consumers in the Iran power industry. One empirical implication has obtained from model performance in the electricity supply chain. The results indicate approximately, the oil and gas fields, the power plants and the distribution lines and the public divisions of power consumers have earned 100%, 90% and 90% efficiency of the total in supply chains, respectively. Particularly, this study recommends that transmission and distribution companies must have adequate decisional capacities regarding investment for transmitting power to industrial, agriculture divisions in the power industry.

Keywords: natural disposability; managerial disposability; Dual-role factors; sustainability; invers flow; technology innovation; environmental efficiency

1. Introduction

An electricity supply chain is a network of suppliers, producers, transmitters and distributors in which raw materials are transformed into final products and delivered to the customers. The Energy sector is one of the most important types of developed infrastructures in any country. The fossil fuels are energy sources of incompatible with the environment so that they emissions various pollutions and greenhouse gases in economics activities. The flare gas emission is one of the most critical problems in oil and gas fields. According to published statistics in the year 2017, daily 4 million oil barrels produced in Iran oil fields and about 45 million cubic meters associated gas (gas in oil) have been burned to avoid from the possible explosion in oil and gas fields that burning fossil fuels not only a big thread for human health and the other organisms but also cause decrease economic return in industrial activities. The repairs problems respect to strengthening pressure systems of associated gas (gas in oil) lead burning the large quantities of gas in oil fields. The problems such as the lack of enough education of the workforce or the lack of pieces timely preparation cause wasting the amount considerable energy in the energy industry. Also, the burned gases release more than 250 toxic substances in the air. Moreover, the associated gas can be used in Liquid petrol gas (LPG) production for car and urban consumptions, power production and chemical and petrochemical derivatives production. Besides, the associate gas can be injected into oil reservoirs to the rehabilitation of thanks and prevention from drying oil reservoirs. Similarly, Power plants from production to consumption produce kinds of contaminations in the environment. Power plants are the largest fossil fuel consumers such as coal, fuel oil and gasoline and natural gas. The sixty–eight percent of the Iran power plants are non-renewable and they consume fossil fuels to power production. These fuels have been playing most of the key role in electricity production and release a huge amount of pollution substance in the production process. Hence, this is immediately necessary to enhance efficiency by the protection of the negative impacts of economic activities. The carbon dioxide gas (CO_2) has the most contributions to pollution emissions in power plants. This gas cause climate changes and global warming also it is a threat to human health and other organisms. Therefore, we must reduce the number of greenhouse gases (GHG) by enhancing systems efficiently, otherwise, we will confront sever events such as heat waves, droughts, floods and other harmful factors to social and economics. Approximately, one percent of power plants' nominal capacity is devoted to power losses in transmission and distribution lines. The one percent of power plant capacity is equivalent to 2.5 billion kilowatt-hour power that to produce this amount of electricity releases about 1.8 ton Carbon dioxide (CO_2) in air. Therefore, a profit solution to this problem is new ideas performance to investment opportunities and Technology innovation to harmful effects protection of environmental.

In other words, if supply chain enterprises equipped with improved engineering capability and invest in improvement and repair of equipment in the divisions then undesirable outputs considerably decrease in production activities. Therefore, supply chain management should enable propose an appropriate approach to wasted energy harness to environmental efficiency enhancement in the power industry. Besides, power plants produce power also they need electricity to power regulations. The inner electricity consumption of power plants divided into technical and non-technical consumptions. The power station generators plant voltage regulators to control the output of power plants in an electric power distribution system. The voltages regulators install at power plants to power transmission with steady voltage and they may be installed at distribution lines to customers receive steady voltage. Therefore, the control of the electricity consumption of power plants can significantly enhance unified efficiency (operational and environmental) in power stations. Data envelopment analysis (DEA) is a profitable method to performance new ideas to investment opportunities and Technology innovation to harmful effects protection of environmental. Let us now suppose that supply chain divisions apply inputs to produce desirable and undesirable outputs as the inputs separate into two categories under natural and managerial disposability. Also, Let us consider undesirable outputs such as emissions of harmful substances in the air, water and ground and other detrimental variables of production activities. Besides, certain factors are considered to simultaneously play the role of both inputs and outputs in production processes. These factors are called dual-role factors. Also, the material flow is transferred from suppliers to manufacturers and from manufacturers to transmitters and from them to distributors and finally from distributors to customers in the production processes. Also, intermediate measures flow between divisions of two consecutive steps in the two inverse directions. Furthermore, the inverse intermediate measures exit from transmitter divisions and enter to manufacture divisions and exit from manufacture divisions and enter to supplier divisions.

In this study, we are going to answer the following questions: how a decision-making unit or a supply chain enables decrease pollution gases emissions by investment on specialist workforce and flare gas recovery systems in oil and gas fields and the new technology innovation in non-renewable power plants and handling wasted energy by engineer workforce as power losses noticeable abatement in transmission and distribution lines? In this case, supply chain management should be able to identify whether inputs increase under managerial disposability to new technology innovation reduce undesirable productions in the electricity supply chain divisions or the increase inputs for investment ineffective for decrease a number of undesirable outputs. Also, it is immediately necessary to know whether the investment can effectively decrease the amount of undesirable outputs or increase the inputs under managerial disposability have a limited effect on decrease an amount of undesirable outputs. Moreover, the supply chain management needs information related to investment effect to the inputs level control under managerial disposability as handling flare gas in energy sections and reducing pollution emissions and greenhouses gases in power plant sectors and harnessing energy wasted in transmission and distribution networks. Furthermore, how the factors to simultaneously play the role of both inputs and outputs can be applied to the costs flare gas control in energy sections and the inner electricity consumption (technical and non-technical) management in power plant sectors and wasted energy harness in distribution lines. In this study, managerial disposability is accomplished by investment into the Energy section to flare gas reduction and environmental protection, construction and initiation of renewable power plants to pollution emissions prevention in the power plant section. Meanwhile, transmission and distribution lines are equipped with improved engineering capability to power losses reduction. Also, dual-role factors control the cost recovery of flare gas in energy sections and the inner electricity consumption of power plants (technical and non-technical) and increase the scientific level of staff to the power losses harness in transmission operation. In current paper applied two concepts of natural and managerial disposability to environmental assessment as the inputs separate into two categories under natural and managerial disposability. Furthermore, we consider natural and managerial disposability to inputs and free disposability of undesirable outputs and weak disposability of desirable outputs so that we calculate a supply chain inefficiency score in the presence of two categories of inputs, dual-role factors, and desirable and undesirable outputs. In the more details, the divisions of every pair of members belong to a consecutive stage are connected by two sets of intermediate measures in the two inverse ways. Moreover, the inverse intermediate measures enter to divisions are considered as non-discretionary inputs. To include the two concepts of natural and managerial disposability to operational and environmental assessment Fan et al. [1] proposed a radial model based on data envelopment analysis to study on eco-efficiency of industrial parks in china. Sueyoshi et al. [2] presented an environmental assessment on Energy and sustainability by data envelopment analysis. Wang et al [3] are calculated operational and environmental efficiency in China' thermal power industry by a global fractional model as taking effectiveness measure as a complement to an efficiency measure. Zhang et al. [4] proposed a three-stage model based on data envelopment analysis. They calculated industrial eco-efficiency of 30 provinces in china. Moreover, the other research studies are presented to the management of greenhouse gases emissions in the production chain [5] and the control of renewable energy [6] and energy management in hybrid electrical vehicle [7].

The remainder of this paper is organized as follows: In Section 2, we present an appropriate literature review on how DEA has been used for research on investment opportunities and technology innovation. Also, it is indicated, the literature summary on the presence of a dual-factors role in Data Envelopment Analysis. Moreover, we present a DEA model for resource utilization and investment in technology innovation. We show how correctly specify natural and managerial disposability in a production processes model of supply chain performance evaluation problems. Section 3 is devoted to introducing a procedure to calculate supply chain efficiency in the presence of two categories of inputs, undesirable products, and dual-role factors and the two set intermediate measures. In Section 4, we present a case study to demonstrate the applicability of the proposed method to the Iran power industry. In Section 5, we present our conclusions.

2. Literature review

In the following subsections, various studies on Environmental and operational assessment and green supply chain management (GSCM), and dual-role factors are briefly summarized.

2.1. Environmental and operational assessment

To include the two concepts of natural and managerial disposability to environmental assessment in the technology and account for the harmful substances prevention and negative impact on productivity Sueyoshi and Golver [8] discussed the history of DEA from the contributions of Cooper who first invented DEA in the 19 century.

Gotto et al. [9,10] proposed a description of the conventional uses of DEA for environmental assessment. Then the concept of natural and managerial disposability has applied as a conceptual basis for preceding research efforts, see for example [11].

Sueyoshi et al. [12] proposed a stage DEA model to operational and environmental assessment of Japanese industrial sectors. They calculated a unified efficiency score under natural and managerial disposability of the decision-making unit by resource utilization and technology innovation.

2.2. Green supply chain management (GSCM)

Kao [13] modified the conventional DEA model by taking into account the series relationship of the two sub-processes within the whole process. Ton and Tustusi [14] proposed a slacks-based network DEA model called network SBM.

Khalili et al. [15] proposed the fuzzy model for measurement of efficiency in transformation process of supply chain agility.

Toloo et al. [16] proposed the DEA approach with mixed integer programming model to determine the most efficiency supplier without imprecise data.

Tavana et al. [17] extended the EBM model proposed by Ton et al. [14] and proposed a new Network EBM (NEMB).

Mahdiloo et al. [18] used the DEA model and DMUs by employing better integration of environmental and technical efficiency objective. They measured environmental, technical and eco-efficiency for supplier selection. The researchers have showed that all previous models are computationally cannot measure eco-efficiency in the best way. They Proposed the new model provide a valid eco-efficiency indicator of DMUs by utilizing a better combination of the technical and environmental efficiency.

Tajbakhsh et al. [19] proposed a multi-stage data envelopment analysis model to evaluate the sustainability of a chain of business partners. They assess supply chain sustainability in the banking sector and beverage case.

Khodakerami et al. [20] proposed the DEA new two stages model of supply chain sustainability in resin producing companies. The authors considered performance measurement of some imprecise and uncertain problems related to in real life as this problem needs to use fuzzy set in DEA model.

Devika et al. [21] applied DEA approach for measurement of the pareto frontier quality. They have considered the social impact with economics and environmental impacts on class producer, simultaneously.

Nikfarjam et al. [22] propose the new method DEA for measuring the supply chain with integrated to approaches. They showed the proposed model can use for evaluating of performance for identify the benchmarking units for inefficiency supply chain.

Babazadeh et al. [23] used DEA approach to evaluate the social and climate criteria in cultivation areas. They evaluated strategic design of biodiesel supply chain network by integration of DEA and mathematical programming. Besides, the authors believe there is lack in previous studies which did not focus on climatic and social criteria and proposed a new DEA model related to biodiesel supply chain planning.

Pouralizadeh et al. [24] proposed a new DEA-based model to sustainability evaluate an electricity supply chain in presence undesirable outputs. They planned a supply chain by five stages and fifteen divisions from different districts in Iran. Also, the weak disposability assumption was adopted for activity level control in production activity. The proposed model enable determents the type and size of inputs to control undesirable outputs.

2.3. Dual-role factors

Toolo [25] proposed a revision of proposed model in [19]. Hatefi et al. [26] proposed a new model based on distance function for classifying inputs and outputs.

Farzipoor [27] proposed a model for selecting third–party reverse logistics providers in the presence of multiple dual role factors and proposed [28] a model for selecting 3PL providers in the presence of both dual-role factors and imprecise data. All of the references mentioned in this subsection do not used network DEA model for GSCM evaluation problem.

Mirhedayrian et al. [29] presented a DEA-based model in the presence of undesirable outputs, dual-role factors, and fuzzy data to a supply chain. They indicated a method to improve environmental performance a green supply chain management and incorporate dual-role factor and undesirable output into (NSBM) model proposed by Tone and Tsutsui [14].

In summary, all of the abovementioned references for environmental performance assessment of the supply chain do not consider network DEA model based on the new technology innovation and targeting investment for the reduction of undesirable products. Also, the aforementioned models to sustainability assessment of supply chain are not able to determine whether the investment effectively decrease the number of undesirable outputs or limited effect on decreasing an amount of undesirable outputs. In other word, the investment may be ineffective for some of supply chain divisions to undesirable outputs abatement.

2.4. The operational and environmental performance assessment

In this Section are reported fundamental concepts for environmental and operational assessment decision-maker unit and the approach to calculate the unified efficiency (operational and environmental) of the electricity supply chain.

2.4.1. The concepts fundamental

Let us suppose $X_j = (x_{1j}, x_{2j}, ..., x_{mj})^T > 0$, $G_j = (g_{1j}, g_{2j}, ..., g_{sj})^T > 0$, $B_j = (b_1, b_2, ..., b_{hj})^T > 0$ presents column vectors of inputs, desirable and undesirable outputs in jth DMU (Decision maker unit), respectively. Sueyoshi and Gotto [5] have proposed a radial model to measure the unified efficiency (operational and environmental) of the kth DMU under natural and managerial disposability of inputs as follows.

$$
\begin{aligned}
&\max\ \xi + \varepsilon[R_i^x d_i^x + R_q^x d_q^x + R_f^x d_f^x] \\
&\sum_{j=1}^{n} x_{ij}^{+}\lambda_j + d_i^x \qquad = x_{ik}^{-} \qquad i = 1,...,m^{-} \\
&\sum_{j=1}^{n} x_{iq}^{+}\lambda_j - d_q^x \qquad = x_{qk}^{+} \qquad q = 1,...,m^{+} \\
&\sum_{j=1}^{n} g_{rj}\lambda_j + \xi g_{rk} \qquad = g_{rk} \qquad r = 1,...,s \\
&\sum_{j=1}^{n} b_{fj}\lambda_j - d_f^b \qquad = b_{fk} \qquad f = 1,...,h \\
&\sum_{j=1}^{n} \lambda_j = 1 \\
&\lambda_j \ge 0,\ j = 1,...,n,\ \ \xi\, URS,\ \ d_i^x \ge 0,\ i = 1,...,m^{-} \\
&d_q^x \ge 0,\ q = 1,...,m^{+},\ \ d_f^b \ge 0,\ f = 1,...,h
\end{aligned}
\tag{1}
$$

In this model, the number of original m inputs are separated into two categories m^{-} (under natural disposability) and m^{+} (under managerial disposability), respectively. The model maintains $m = m^{-} + m^{+}$. Also, ξ is an inefficiency score that measures the distance between efficiency frontier and one observed vector of the desirable outputs and d_i^x, d_q^x, d_f^b are slack variables belong to two categories input and undesirable output, respectively. In addition, ε is a small amount and it considered as 0.0001 for our computation convenience it is possible for model to use $\varepsilon = 0$ in model (5). In this model R_i^x, R_q^x, R_f^b are specified by decision maker as fallows.

$$
\begin{aligned}
R_i^x &= (m+s+h)^{-1}\left(\max\left\{x_{ij} \mid j = 1,...,n\right\} - \min\left\{x_{ij} \mid j = 1,...,n\right\}\right)^{-1} \\
R_q^x &= (m+s+h)^{-1}(\max\left\{x_{qj} \mid j = 1,...,n\right\} - \min\left\{x_{qj} \mid j = 1,...,n\right\})^{-1} \\
R_f^b &= (m+s+h)^{-1}\left(\max\left\{b_{fj} \mid j = 1,...,n\right\} - \min\left\{b_{fj} \mid j = 1,...,n\right\}\right)^{-1}
\end{aligned}
\tag{2}
$$

The column vectors of structural variables (λ) are applied for connecting the input and output vectors by convex combination under variable return scale. A unified efficiency score under natural and managerial disposability is measured as follows

$$
UEMN = 1 - \left[\xi^{*} + \varepsilon\left(\sum_{i=1}^{m^{-}} R_i^x d_i^{x*} + \sum_{q=1}^{m^{+}} R_q^x d_q^{x*} + \sum_{f=1}^{h} R_f^b d_f^{b*}\right)\right]
\tag{3}
$$

where the inefficiency score and all slack variables are determined on the optimality of Model (1).

3. Methodology

3.1. Weak, strong, natural and managerial disposability of the supply chain divisions

The weak disposability concept has specified on two outputs vectors of hth division, (G^h, B^h) as follows:

$$P_w^h(x) = \left\{ (G^h, B^h) : G^h \leq \sum_{j=1}^{n} G_j^h \lambda_j^h,\ B^h = \sum_{j=1}^{n} B_j^h \lambda_j^h\ ,\ X^h \geq \sum_{j=1}^{n} X_j^h \lambda_j^h\ , \sum_{j=1}^{n} \lambda_j^h = 1\ , (j = 1, \ldots, n) \right\} \tag{4}$$

Subscript,(j) shows jth (DMU) and λ_j indicates the jth intensity variable (j = 1,…,n). The inequality constraints ($X^h \geq \sum_{j=1}^{n} X_j^h \lambda_j^h$), ($G^j \leq \sum_{j=1}^{n} G_j^h \lambda_j^h$) indicates strong disposability on inputs and desirable outputs from hth division, respectively and $B^h = \sum_{j=1}^{n} B_j^h \lambda_j^h$ measures congestion on undesirable outputs from hth division. Similarity, strong disposability is specified on the two output vectors as follows.

$$P_s^h(x) = \left\{ (G^h, B^h) : G^h \leq \sum_{j=1}^{n} G_j^h \lambda_j^h,\ B^h \leq \sum_{j=1}^{n} B_j^h \lambda_j^h\ ,\ X^h \geq \sum_{j=1}^{n} X_j^h \lambda_j^h\ , \sum_{j=1}^{n} \lambda_j^h = 1\ , (j = 1, \ldots, n) \right\} \tag{5}$$

The inequality constraint $B \leq \sum_{j=1}^{n} B_j \lambda_j$ allow for strong disposability on undesirable outputs. The constraint $\sum_{j=1}^{n} \lambda_j = 1$ is incorporated into the two expressions which indicate variable return to scale in production processes. The production technology set to definition of natural and managerial Disposability is specified by the following two types of output vectors and an input vector for hth division of the supply chain as follows.

$$P_N^h(x) = \left\{ (G^h, B^h) : G^h \leq \sum_{j=1}^{n} G_j^h \lambda_j^h, B^h \leq \sum_{j=1}^{n} B_j^h \lambda_j^h\ , X^h \geq \sum_{j=1}^{n} X_j^h \lambda_j^h\ , \sum_{j=1}^{n} \lambda_j^h = 1\ , (j = 1, \ldots, n) \right\} \tag{6}$$

$$P_M^h(x) = \left\{ (G^h, B^h) : G^h \leq \sum_{j=1}^{n} G_j^h \lambda_j^h, B^h \leq \sum_{j=1}^{n} B_j^h \lambda_j^h\ , X^h \leq \sum_{j=1}^{n} X_j^h \lambda_j^h\ , \sum_{j=1}^{n} \lambda_j^h = 1\ , (j = 1, \ldots, n) \right\} \tag{7}$$

Here $P_N^h(x)$ is defined as a production possibility set under natural (N) disposability and $P_M^h(x)$ managerial (M) disposability one from hth division. The production technology under natural disposability or $P_N^h(x)$ has $X^h \geq \sum_{j=1}^{n} X_j^h \lambda_j^h$ mentioned an organization can reduce a directional vector of input to attain to efficiency frontier. Likewise, The production technology under managerial disposability or $P_M^h(x)$ has $X^h \leq \sum_{j=1}^{n} X_j^h \lambda_j^h$ mentioned a directional vector of inputs from hth division of the supply chain can increase to attain to the efficient frontier. The both of production technology set have common constraints, $G^h \leq \sum_{j=1}^{n} G_j^h \lambda_j^h$, $B^h \leq \sum_{j=1}^{n} B_j^h \lambda_j^h$ under natural and managerial disposability.

3.2. Modeling of investment effective for technology innovation of supply chain divisions

Let us consider the general structure of the supply chain depicts in Figure 1. Let us consider, x_{mj}^h, g_{rj}^h, b_{fj}^h , w_{ej}^h indicate mth input $(m = 1,\ldots,M)$, rth desirable outputs $(r = 1,\ldots,S)$ and fth undesirable outputs ($f = 1,\ldots,F$) and eth dual-role factors ($e = 1,\ldots,E$) of hth division $(h = 1,\ldots,H)$ in jth ($j = 1,\ldots,n$) supply chain, respectively. Also, $\bar{x}_{mj}^h$, $\tilde{x}_{mj}^h$ indicate original m inputs are separated into two categories m^- and m^+, as $M = m^- + m^+$. Furthermore, $v_{pj}^{(h,h')}$ represent the intermediate measures between the hth division to the h'th division of jth supply chain. The subscript (p, j) indicating pth intermediate measure $(p = 1,\ldots,P_h)$ in jth supply chain $(j = 1,\ldots,n)$ and $z_{aj}^{(h',h)}$ represent invers intermediate measures exit from h'th division and enter to hth division. The subscript (a, j) indicating ath intermediate measure $(a = 1,\ldots,A_h)$ in jth supply chain. $(j = 1,\ldots,n)$.

The production technology set of hth division in the jth supply chain is defined as follows: $Y = \left\{\left(v_j^h,\ z_j^h, g_j^h, b_j^h, w_j^h\ x_j^h\right) \middle|\ x_j^h\ can\ produce\left(v_j^h, z_j^h, y_j^h, w_j^h\right)\right\}$. Thus, the outputs set of hth division in the jth supply chain can be indicated as follows:

$P_j^h(x) = \left\{ \left(v_j^h, z_j^h, g_j^h, b_j^h, w_j^h\right) \middle| \left(v_k^h, z_j^h, g_j^h, b_j^h, w_j^h, x_j^h\right) \in Y \right\}$

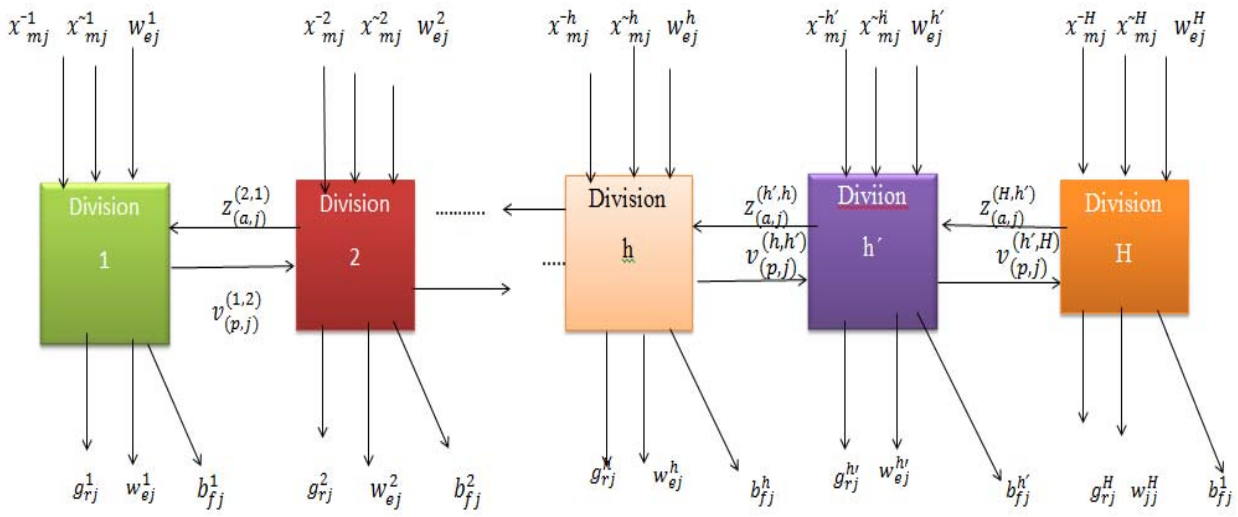

Figure 1. The general structure of supply chain.

Let us now suppose a supply chain (DMU) is concluded from five-stage, supplier, Manufacture, transmitter, distributor, and customer. We treat each supply chain as a DMU. Let us consider h_s, h_m, h_t, h_d, h_c the number of divisions in the supplier, manufacturer, transmitter, distributor and customer. Figure 2 shows an electricity supply chain structure in the power industry. The electricity supply chains are power suppliers in power production activities. They are comprised of fuel suppliers (oil and gas fields), power producers (power plants), electricity transmitters (transmission lines), power distributors (distribution lines) and final customers. These entities collaborate to power production and management in economic business.

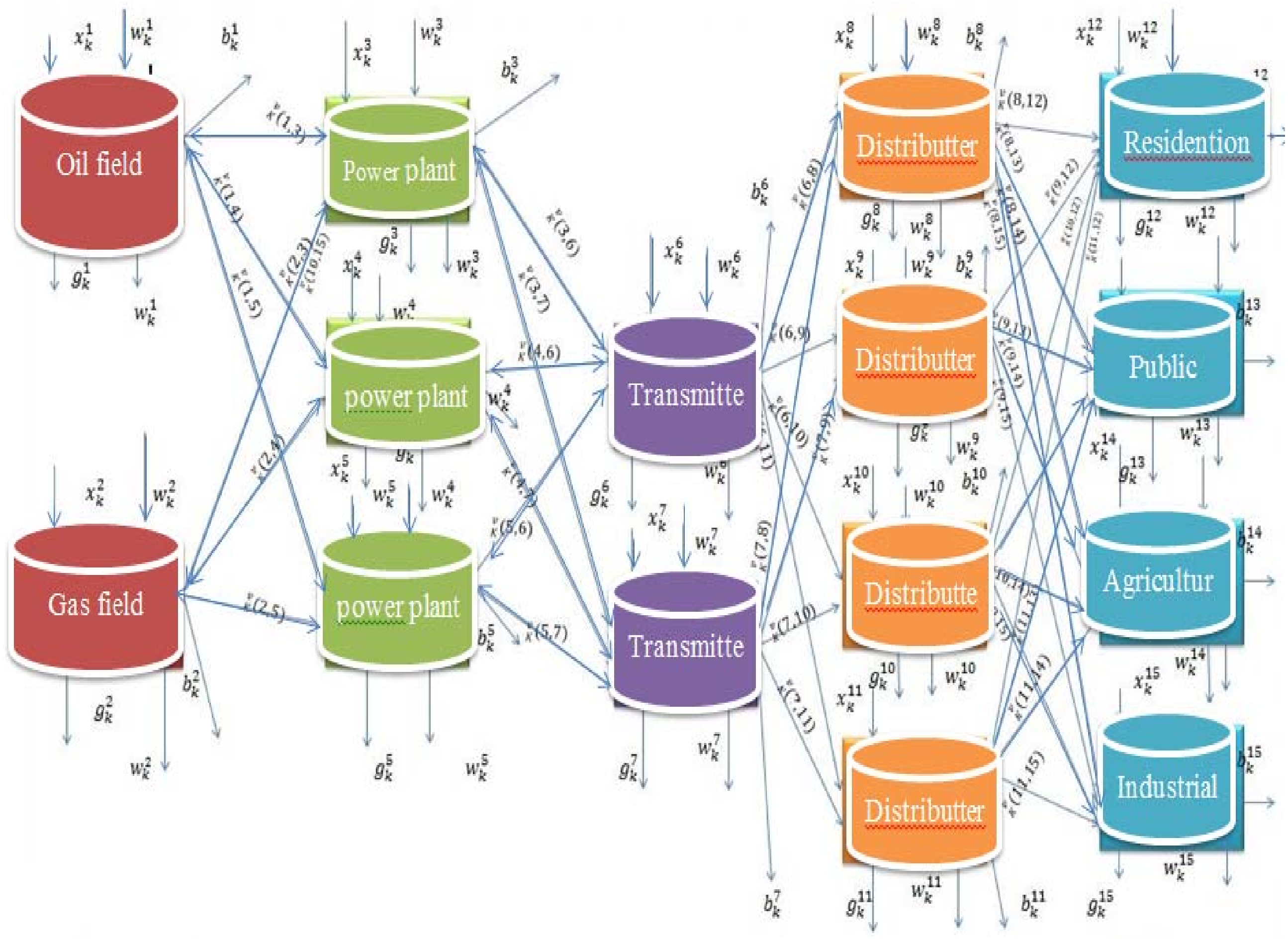

Figure 2. The supply chain structure.

In this study, the supply chains have been built in northern, southern, eastern, western and central districts in Iran. In this conformation Oil and gas fields and refineries provide demand fuels of power plants and district power plants Transfer produced power by regional power companies to the area distribution companies to dispatching to consumers or residents of their area. Other words, each supply chain or DMU is built of five stages and partners of each stage connected by intermediate measures to the successor stage. Supply chains are comparable and compete in the power industry. In Figure 2 is depicted intermediated measures sent from oil and gas fields to power plants, from power plants to transmissions companies, from transmissions companies to distributions companies and finally from them to customers. Furthermore, the inverse intermediate measures exit from transmitter divisions and enter to manufacture divisions and exit from manufacture divisions and enter to supplier divisions. These measures indicate entities' relationship in the supply chain. However, each division of entities operates independent from other divisions of per stage in production activities and supply chains compete to high efficiency earn in economic business (see Pouralizadeh et al. [24]).

3.3. The proposed model

In this section, we propose a DEA model to sustainability assessment a supply chain. We suppose a supply chain contains an arbitrary number of suppliers, manufacturers, transmitters, distributors and customers. The model (1) be further developed as a network model by incorporate the two categories intermediate measures and dual-role factors for each supply chain division in order to efficiency assessment of the overall supply chain.

We shall assume the inputs separate into two categories under natural and managerial disposability, weak disposability of good outputs reduction, free disposability of undesirable outputs and convexity and variable returns to scale in the production process to calculate inefficiency score. In this study we considered the different weights for partners of a particular stage of the network supply chain as $w_h, (h = 1,\dots,H)$ are weights for H divisions that are defined by decision-makers in production activities. In this method, the inefficiency performance evaluating of an overall supply chain can be formed by the inefficiency performance evaluating of all its divisions similar to model (1). The production factors of the jth supply chain (DMU) are summarized as follows:

$\bar{X}_j^h = (\bar{x}_{1j}^h, \bar{x}_{2j}^h, \dots, \bar{x}_{ij}^h)^T > 0$: The input ith under natural disposability from hth division in jth supply chain, $i = 1,\dots,m^-$, $h = 1,\dots,H$, $j = 1,\dots,n$.

$\tilde{X}_j^h = (\tilde{x}_{1j}^h, \tilde{x}_{2j}^h, \dots, \tilde{x}_{qj}^h)^T > 0$: The input qth under managerial disposability from hth division in jth supply chain, $q = 1,\dots,m^+$, $h = 1,\dots,H$, $j = 1,\dots,n$.

$G_{rj}^h = (g_{1j}^h, g_{2j}^h, \dots, g_{rj}^h)^T > 0$: The desirable output rth from hth division in jth supply chain $r = 1,\dots,s,\ h = 1,\dots,H,\ j = 1,\dots,n$.

$B_j^h = (b_{ij}^h, b_{2j}^h, \dots, b_{fj}^h)^T > 0$: The undesirable output fth from hth division in jth supply chain $f = 1,\dots,F,\ h = 1,\dots,H,\ j = 1,\dots,n$.

$W_j^h = (w_{1j}^h, w_{2j}^h, \dots, w_{ej}^h)^T > 0$: The dual-role factor eth from hth division in jth supply chain $e = 1,\dots,E,\ h = 1,\dots,H,\ j = 1,\dots,n$.

$V_j^{(h,h')} = (v_{1j}^{(h,h')}, v_{2j}^{(h,h')}, \dots, v_{pj}^{(h,h')})^T > 0$: The pth Material flow or intermediate measure from division h to division h' in jth supply chain, $p = 1,\dots,P,\ h = 1,\dots,H,\ j = 1,\dots,n$.

$Z_j^{(h',h)} = (z_{1j}^{(h',h)}, z_{2j}^{(h',h)}, \dots, z_{aj}^{(h',h)})^T > 0$: The ath invers intermediate measure from division h' to division h in jth supply chain, $a = 1,\dots,A,\ h = 1,\dots,H,\ j = 1,\dots,n$.

$s_{pj}^{(h,h')}$: The slack variables of the pth intermediate measure from divisions h to divisions h' in jth supply chain, (p = 1,…,P), (j = 1,…,n).

$s_{aj}^{-(h',h)} \geq 0$: The input slack variables of the ath invers intermediate measure from division h' to division h in jth supply chain (a = 1,…,A), (j = 1,…,n).

$s_{aj}^{+(h',h)} \geq 0$: The output slack variables of the ath intermediate measure or invers flow from division h' to division h in jth supply chain (a = 1,…,A), (j = 1,…,n).

$\lambda^h = (\lambda_1^h, \lambda_2^h, ..., \lambda_n^h)^T$: An unknown column vector.

$R_i^h = (M_h + S_h + F_h + E_h + D_h)^{-1} \left(\max\left\{ x_{ij}^h \,|\, j = 1,...,n \right\} - \min\left\{ x_{ij}^h \,|\, j = 1,...,n \right\} \right)^{-1}$: A data range related to i th input in hth division. $i = 1,\ldots,m^-, h = 1,\ldots,H$.

$R_q^h = (M_h + S_h + F_h + E_h + D_h)^{-1} \left(\max\left\{ x_{qj}^h \,|\, j = 1,...,n \right\} - \min\left\{ x_{qj}^h \,|\, j = 1,...,n \right\} \right)^{-1}$: A data range related to qth input in hth division. $h = 1,...,H$, $q = 1,\ldots,m^+$.

$R_f^h = (M_h + S_h + F_h + E_h + D_h)^{-1} \left(\max\left\{ b_{fj}^h \,|\, j = 1,...,n \right\} - \min\left\{ b_{fj}^h \,|\, j = 1,...,n \right\} \right)^{-1}$: A data range related to f th undesirable output input in hth division. $h = 1,...,H$, $f = 1,...,F$.

$R_p = (M_h + S_h + F_h + E_h + D_h)^{-1} \left(\max\left\{ v_{pj}^{(h,h')} \,|\, j = 1,...,n \right\} - \min\left\{ v_{pj}^{(h,h')} \,|\, j = 1,...,n \right\} \right)^{-1}$: A data range related to p th intermediate measure sent from hth division to h' th divisions. $p = 1,...,P,\ h \neq h',\ h, h' \in \{1,...,H\}$

$R_a = (M_h + S_h + F_h + E_h + D_h)^{-1} \left(\max\left\{ z_{aj}^{(h',h)} \,|\, j = 1,...,n \right\} - \min\left\{ z_{aj}^{(h',h)} \,|\, j = 1,...,n \right\} \right)^{-1}$: A data range related to a th invers intermediate measure sent from sent from h' th division to hth divisions. $a = 1,...,A,\ h \neq h',\ h, h' \in \{1,...,H\}$.

ξ^h : Inefficiency score of hth division.

ε : A small amount and it considered as 0.0001 for computation convenience.

In proposed approach, the number of original m inputs of hth division are separated into two categories, m_h^- (under natural disposability) and m_h^+ (under managerial disposability), respectively. The model maintains $M_h = m_h^- + m_h^+$. Also, $s_p^{(h,h')}$ is slack variable of pth the intermediate measure $(p = 1,...,P)$ sent from hth division to h' th division and, $s_a^{+(h',h)}$ is defined as slack variables of ath the inverse intermediate measures $(a = 1,...,A)$ sent from h' th division to h th division. Also, the inverse intermediate measures enter to divisions are considered as non-discretionary inputs set and, the inverse intermediate measures exits from divisions are specified as desirable outputs set in model. The column vectors of structural variables (λ^h) are applied for connecting the input, desirable and undesirable output vectors, the dual-role factors and the set intermediate measures by convex combination under variable return scale in h th division. $M_h, S_h, F_h, E_h, (h = 1,...,H)$, indicate the total number of inputs, the desirable and undesirable outputs, the dual-role factors in hth division. Also, P_h, A_h show the total number of intermediate measures sent from hth division to the h' th division and the inverse intermediate measures exit from h' th division and enter to hth division (h, $h' : h, h' = 1,...,H$) , respectively.

In proposed model $R_i^h, R_q^h, R_f^h, R_p^h, R_a^h$ are specified by the decision maker for h th division as follows:

$$R_i^h = (M_h + S_h + F_h + E_h + P_h + A_h)^{-1} \left(\max\left\{ \bar{x}_{ij}^h \,|\, j = 1,...,n \right\} - \min\left\{ \bar{x}_{ij}^h \,|\, j = 1,...,n \right\} \right)^{-1}$$

$$R_q^h = (M_h + S_h + F_h + E_h + P_h + A_h)^{-1} \left(\max\left\{ \tilde{x}_{qj}^h \,|\, j = 1,...,n \right\} - \min\left\{ \tilde{x}_{qj}^h \,|\, j = 1,...,n \right\} \right)^{-1}$$

$$R_f^h = (M_h + S_h + F_h + E_h + P_h + A_h)^{-1} \left(\max\left\{ b_{fj}^h \,|\, j = 1,...,n \right\} - \min\left\{ b_{fj}^h \,|\, j = 1,...,n \right\} \right)^{-1}$$

$$R_p^h = (M_h + S_h + F_h + E_h + P_h + A_h)^{-1} \left(\max\left\{ v_{pj}^{(h,h')} \,|\, j = 1,...,n \right\} - \min\left\{ v_{pj}^{(h,h')} \,|\, j = 1,...,n \right\} \right)$$

$$R_a^h = (M_h + S_h + F_h + E_h + P_h + A_h)^{-1} \left(\max\left\{ z_{aj}^{(h',h)} \,|\, j = 1,...,n \right\} - \min\left\{ z_{aj}^{(h',h)} \,|\, j = 1,...,n \right\} \right)^{-1} \quad (8)$$

Moreover, slack variables correspond to inverse intermediate flows that are considered as non-discretionary inputs sets are not include in objective function and their corresponding constraints set is followed by the '*' symbol. Unified efficiency score is obtained by subtracting the level of inefficiency from unity. A unified efficiency score under natural and managerial disposability is measured from the supply chain as follows:

$$UENM = 1 - \left[\xi^* + \varepsilon (R_i^h d_i^{*h} + R_q^h d_q^{*h} + R_f^h d_f^{*h} + \sum_{p=1}^{P} R_p s_p^{*(h,h')} + \sum_{a=1}^{A} R_a S_a^{+*(h',h)}) \right] \quad (9)$$

The objective function of DMU (supply chain) calculates by weighted average of optimal inefficiency of each division of the supply chain so the objective function weights could be obtained through an expert opinion process. Therefore, the inefficiency scores and all slack variables are determined on the optimality model as follows:

$$
\begin{aligned}
&\theta = Max\sum_{h=1}^{H} W_h\,[\,\xi_h + \varepsilon(\sum_{i=1}^{m^-} R_i^h d_i^h + \sum_{q=1}^{m^+} R_q^h d_q^h + \sum_{f=1}^{F} R_f^h d_f^h + \sum_{h'=1}^{H}\sum_{p=1}^{P} R_p s_p^{(h,h')} + \sum_{h'=1}^{H}\sum_{a=1}^{A} R_a s_a^{+(h',h)}\,]\\
&\sum_{j=1}^{n} \bar{x}_{ij}^h \lambda_j^h + d_i^h = \bar{x}_{ik}^h \qquad i=1,\dots,m_h^-,\ h=1,\dots,H\\
&\sum_{j=1}^{n} \tilde{x}_{qj}^h \lambda_j^h - d_q^h = \tilde{x}_{qk}^h \qquad q=1,\dots,m_h^+,\ h=1,\dots,H\\
&\sum_{j=1}^{n} g_{rj}^h \lambda_j^h + \xi^h g_{rk}^h = g_{rk}^h \qquad r=1,\dots,S_h\ ,h=1,\dots,H\\
&\sum_{j=1}^{n} b_{fj} \lambda_j^h - d_f^h = b_{fk}^h \qquad f=1,\dots,F_h\,,h=1,\dots,H\\
&\sum_{j=1}^{n} w_{ej}^h \lambda_j^h = w_{ek}^h \qquad e=1,\dots,E_s\,,h=1,\dots,h_s\\
&\sum_{j=1}^{n} w_{ej}^h \lambda_j^h = w_{ek}^h \qquad e=1,\dots,E_m\,,h=1,\dots,h_m\\
&\sum_{j=1}^{n} w_{ej}^h \lambda_j^h = w_{ek}^h \qquad e=1,\dots,E_t\,,h=1,\dots,h_t\\
&\sum_{j=1}^{n} \lambda_j^h v_{pj}^{(h,h')} + s_p^{(h,h')} = \sum_{j=1}^{n} \lambda_j^{h'} v_{pj}^{(h,h')} \qquad h=1,\dots,h_s\,,p=1,\dots,P_s\,,h'=1,\dots,h_m\\
&\sum_{j=1}^{n} \lambda_j^h v_{pj}^{(h,h')} + s_p^{(h,h')} = \sum_{j=1}^{J} \lambda_j^{h'} v_{pj}^{(h,h')} \qquad h=1,\dots,h_m\,,p=1,\dots,P_m\,,h'=1,\dots,h_t\\
&\sum_{j=1}^{n} \lambda_j^h v_{pj}^{(h,h')} + s_p^{(h,h')} = \sum_{j=1}^{n} \lambda_j^{h'} v_{pj}^{(h,h')} \qquad h=1,\dots,h_t\,,p=1,\dots,P_t\,,h'=1,\dots,h_d\\
&\sum_{j=1}^{n} \lambda_j^h v_{pj}^{(h,h')} + s_p^{(h,h')} = \sum_{j=1}^{n} \lambda_j^{h'} v_{pj}^{(h,h')} \qquad h=1,\dots,h_d\,,p=1,\dots,P_d\,,h'=1,\dots,h_c\\
&\sum_{j=1}^{n} \lambda_j^h z_{aj}^{(h',h)} - s_a^{+(h',h)} = z_{ak}^{(h',h)} \qquad h=1,\dots,h_s,h'=1,\dots,h_m\,,a=1,\dots,A_s\\
&\sum_{j=1}^{n} \lambda_j^h z_{aj}^{(h',h)} + s_a^{+(h',h)} = z_{ak}^{(h',h)} \qquad h=1,\dots,h_s,h'=1,\dots,h_m\,,a=1,\dots,A_m\\
&\sum_{j=1}^{n} \lambda_j^{h'} z_{aj}^{(h',h)} - s_a^{-(h',h)} = z_{ak}^{(h',h)} \qquad h=1,\dots,h_m,h'=1,\dots,h_t\,,a=1,\dots,A_m\\
&\sum_{j=1}^{n} \lambda_j^{h'} z_{aj}^{(h',h)} + s_a^{-(h',h)} = z_{ak}^{(h',h)} \qquad h=1,\dots,h_m,h'=1,\dots,h_t\,,a=1,\dots,A_t \qquad *\\
&\sum_{j=1}^{n} \lambda_j^h = 1 \qquad h=1,\dots,H\,,j=1,\dots,n\\
&\lambda_j \ge 0\ ,\ s_a^{+(h,h')} \ge 0,\ s_a^{-(h,h')} \ge 0,\ s_p^{(h,h')}\,,\ \xi\ UR,\quad j=1,\dots,n,\ h=1,\dots,H
\end{aligned} \tag{10}
$$

Therefore, efficiency score on DMU is measured by $\beta = 1-\theta$ where the inefficiency score and all slack variables correspond to inputs under natural and managerial disposability and undesirable outputs and the two set intermediate measures are determined on the optimality of model (10). In a result, the inefficiency of the overall supply chain can be formed of weighted average of all of its partner's inefficiency in production processes as model (10). The first and second constraints categories correspond to inputs set under natural and managerial disposability, respectively. Also, the third and the fourth constraints categories related to desirable and undesirable outputs, respectively and the fifth, sixth, seventh, constraints categories are correspond to dual-role factors of supplier, manufacture and transmitter divisions. The eighth, ninth, tenth and eleventh the categories constraints correspond to intermediate measures sent from supplier divisions to manufacturer divisions, and manufacturer divisions to transmitter divisions, and from transmitter divisions to distributor divisions and from them to customer divisions, respectively.

The twelfth and thirteenth the categories constraints related to inverse intermediated measures exit from manufacturer divisions and enter to supplier divisions. Also, the fourteenth and fifteen the categories constraints correspond to inverse intermediate measures exit from transmitter divisions and enter to manufacture divisions. The last constraints categories related to variable returns to scale in the production process. This model measures an investment opportunity for technology innovation for reducing the number of industrial pollutions (flaring gas) in oil and gas fields and power plants sectors and preventing from power losses in transmission and distribution lines. Moreover, these approaches examine the level of unified efficiency by a single inefficiency score that is assigned to desirable outputs. Meanwhile, constraints on the desirable output $\sum_{j=1}^{n} g_{rj}^{h}\lambda_j^h + \xi^h g_{rk}^h = g_{rk}^h$ do not have any slack so that they can be considered as equality, so belonging to weak disposability and other constraints relate to inputs and undesirable outputs maintain slacks in the model (10). Thus, these constraints on all inputs and undesirable output are considered as inequality, so implying the concept of strong disposability.

3.4. The effects of investment for undesirable outputs decrease

Let us suppose, $t_i^h (i=1,...,m^-)$, $l_q^h (i=1,...,m^+)$, $u_r^h (r=1,...,s)$, $c_f^h (f=1,...,F)$, $y_e^h (e=1,...,E)$, present the dual variables correspond to the categories constraints of the inputs under natural and managerial disposability, desirable and undesirable outputs and dual-role factors from hth division, $(h=1,...,H)$ in the model(10), respectively. Moreover, let us consider, $\bar{B}_p$, B'_p, $\tilde{B}_p$ $\hat{B}_p$ the dual variables correspond to eighth, ninth, tenth and eleventh of the categories constraints related to intermediate measures which are sent from the supplier divisions to manufacture divisions and from manufacture divisions to transmitter divisions and from them to distributor divisions finally from distributer divisions to customer divisions, respectively. Likewise, we suppose $\bar{I}_a$, I'_a, $\tilde{I}_a$, $\hat{I}_a$, present the dual variables related to the twelfth, thirteenth, fourteenth and fifteen of the categories constraints of inverse intermediate measures which exit from manufacture divisions, entire to supplier divisions and exit from transmitter divisions and entire to manufacture divisions, respectively. Furthermore, the dual variable σ^h is obtained from the last equation from the model (10) in hth division.

The dual formulation of model (10) is as follows:

$$
\begin{aligned}
&\min Z=\sum_{h=1}^{H}\Big(\sum_{i=1}^{m-}t_i^h\bar{x}_{ik}^h-\sum_{q=1}^{m+}l_q^h\tilde{x}_{qk}^h+\sum_{r=1}^{S}u_r g_{rk}^h-\sum_{f=1}^{F}c_f b_{fk}^h+\sum_{e=1}^{E}y_e^h w_{ek}^h+\sum_{h'=h_m}\sum_{a=1}^{A}\bar{I}_a z_{ak}^{(h',h)}+\sum_{h'=h_t}\sum_{a=1}^{A}\hat{I}_a z_{ak}^{(h',h)}+\sigma^h\Big)\\
&s.t\sum_{i=1}^{m-}t_i^h\bar{x}_{ij}^h-\sum_{q=1}^{m+}l_q^h\tilde{x}_{qj}^h+\sum_{r=1}^{S}u_r g_{rj}^h-\sum_{f=1}^{F}c_f b_{fj}^h+\sum_{e=1}^{E}y_e^h w_{ej}^h+\sum_{p=1}^{P}\bar{B}_p v_{pj}^{(h,h')}+\sum_{a=1}^{A}I'_a z_{aj}^{(h',h)}+\sigma^h\ge 0\\
&\qquad h=1,\ldots,h_s,\quad h'=1,\ldots,h_m,\quad j=1,\ldots,n\\
&\sum_{i=1}^{m-}t_i^h\bar{x}_{ij}^h-\sum_{q=1}^{m+}l_q^h\tilde{x}_{qj}^h+\sum_{r=1}^{S}u_r g_{rj}^h-\sum_{f=1}^{F}c_f b_{fj}^h+\sum_{e=1}^{E}y_e^h w_{ej}^h+\sum_{p=1}^{P}B'_p v_{pj}^{(h,h')}-\sum_{p=1}^{P}\bar{B}_p v_{pj}^{(h,h')}+\sum_{a=1}^{A}\bar{I}_a z_{aj}^{(h,h'')}+\sum_{a=1}^{A}\tilde{I}_a z_{aj}^{(h,h')}++\sigma^h\ge 0\\
&\qquad h=1,\ldots,h_m,\quad h'=1,\ldots,h_t,\quad h''=1,\ldots,h_s,\quad j=1,\ldots,n\\
&\sum_{i=1}^{m-}t_i^h\bar{x}_{ij}^h-\sum_{q=1}^{m+}l_q^h\tilde{x}_{qj}^h+\sum_{r=1}^{S}u_r g_{rj}^h-\sum_{f=1}^{F}c_f b_{fj}^h+\sum_{e=1}^{E}y_e^h w_{ej}^h+\sum_{p=1}^{P}\tilde{B}_p v_{pj}^{(h,h')}-\sum_{p=1}^{P}\bar{B}_p v_{pj}^{(h,h')}+\sum_{a=1}^{A}\tilde{I}_a z_{aj}^{(h,h'')}+\sigma^h\ge 0\\
&\qquad h=1,\ldots,h_t,\quad h'=1,\ldots,h_d,\quad h''=1,\ldots,h_m,\quad j=1,\ldots,n\\
&\sum_{i=1}^{m-}t_i^h\bar{x}_{ij}^h-\sum_{q=1}^{m+}l_q^h\tilde{x}_{qj}^h+\sum_{r=1}^{S}u_r g_{rj}^h-\sum_{f=1}^{F}c_f b_{fj}^h+\sum_{e=1}^{E}y_e^h w_{ej}^h+\sum_{p=1}^{P}\hat{B}_p v_{pj}^{(h,h')}-\sum_{p=1}^{P}\tilde{B}_p v_{pj}^{(h,h')}+\sigma^h\ge 0\\
&\qquad h=1,\ldots,h_d,\qquad h'=1,\ldots,h_c,\quad j=1,\ldots,n\\
&\sum_{i=1}^{m-}t_i^h\bar{x}_{ij}^h-\sum_{q=1}^{m+}l_q^h\tilde{x}_{qj}^h+\sum_{r=1}^{S}u_r g_{rj}^h-\sum_{f=1}^{F}c_f b_{fj}^h+\sum_{e=1}^{E}y_e^h w_{ej}^h+\sigma^h\ge 0\\
&\qquad h=1,\ldots,h_c,\qquad\qquad j=1,\ldots,n\\
&\sum_{r=1}^{S_h}u_r^h g_{rk}^h=W^h \qquad h=1,\ldots,H\\
&t_i^h\ge W^h\varepsilon R_i^h \qquad i=1,\ldots,m_h^-,\ h=1,\ldots,H,\\
&l_q^h\ge W^h\varepsilon R_q^h \qquad q=1,\ldots,m_h^+,\ h=1,\ldots,H\\
&c_f^h\ge W^h\varepsilon R_f^h \qquad f=1,\ldots,F_h,\ h=1,\ldots,H\\
&\bar{B}_p=W^{h_s}\varepsilon R_p^{(h,h')} \qquad p=1,\ldots,P,\ h=1,\ldots,h_s,\ h'=1,\ldots,h_m\\
&B'_p=W^{h_m}\varepsilon R_p^{(h,h')} \qquad p=1,\ldots,P,\ h=1,\ldots,h_m,\ h'=1,\ldots,h_t\\
&\tilde{B}_p=W^{h_t}\varepsilon R_p^{(h,h')} \qquad p=1,\ldots,P,\ h=1,\ldots,h_t,\ h'=1,\ldots,h_d\\
&\hat{B}_p=W^{h_d}\varepsilon R_p^{(h,h')} \qquad p=1,\ldots,P,\ h=1,\ldots,h_d,\ h'=1,\ldots,h_c\\
&I'_a\ge W^{h_m}\varepsilon R_a^{(h',h)} \qquad a=1,\ldots,A_m,\ h'=1,\ldots,h_m,\ h=1,\ldots,h_s\\
&\hat{I}_a\ge W^{h_t}\varepsilon R_a^{(h,h')} \qquad a=1,\ldots,A_t,\ h'=1,\ldots,h_t,\ h=1,\ldots,h_m\\
&\bar{I}_a\ge 0 \qquad a=1,\ldots,A_s\\
&\tilde{I}_a\ge 0 \qquad a=1,\ldots,A_m\\
&u_r^h,\ y_e^h,\ \bar{B}_p, B'_p, \tilde{B}_p, \hat{B}_p, \sigma^h: URS,\quad \forall h=1,\ldots,H
\end{aligned}
\tag{11}
$$

According to model (10) the supporting hyper plane is expressed for an arbitrary division from power customers as follows:

$$t^h\,\bar{x}^h-l^h\tilde{x}^h+u^h\,g^h-c^h\,b^h\ +w^h\,y^h\ +\sigma^h=0 \qquad h=1,\ldots,h_c \tag{12}$$

In this case, all production factors have a single component. The concept of DTR defined as $(db/dg)_h\,/\,(b/g)_h$ for hth division in the case a single component of the two production factors. Based upon the sign of $(db/dg)_h\,/\,(b/g)_h$ the type of a supporting hyper plane is specified for an arbitrary division from power customers on desirable output (g) and undesirable output (b) as follows:

(a) If $(db/dg)_h\,/\,(b/g)_h>0$ then the DTR is as positive

(b) If $(db/dg)_h\,/\,(b/g)_h=0$ then the DTR is as zero.

(c) If $(db/dg)_h / (b/g)_h < 0$ then the DTR is as negative.

After solving the Model (11) the desirable outputs congestion or technology innovation for hth division is identified under assumption of a unique optimal solution by the dual variables correspond to desirable output constraints as follows:

(a) If $(u_r^h)^* = 0$ for some (at least one) r then the 'zero DTR' occurs on hth division from the supply chain under consideration.

(b) If $(u_r^h)^* < 0$ for some (at least one) r then the 'negative DTR' occurs on hth division from the supply chain under consideration.

(c) If $(u_r^h)^* > 0$ for all r then the 'positive DTR' occurs on hth division from the supply chain under consideration.

Note, If $(u_r^h)^* < 0$ some r and $(u_r^h)^* = 0$ for other r, then we consider that the negative DTR occurs on hth division from the supply chain under consideration. In other words, this case indicates a status of desirable congestion or technology innovation on undesirable outputs. Furthermore, if $(u_r^h)^* < 0$ for all r then, this case indicates the best status because technology innovation increase all of the desirable outputs and increase in any desirable output always abatement undesirable outputs. Furthermore, If $(u_r^h)^* < 0$ is defined for some r, then it indicates a case to abatement an amount of undesirable outputs. Therefore, the effect of investment is specified by the dual variable $(z_q^h)^*$ as if $(z_q^h)^* > W\varepsilon R_q^h$ then the qth the input for investment under managerial disposability able to decrease the amount of undesirable output in hth division and if $(z_q^h)^* = W\varepsilon R_q^h$ then the qth the input has a limited effect on reducing of undesirable output.

4. A real case on the power industry

In this section we apply the proposed model to the analysis of the power industry in Iran. In Subsection 4.1 we will describe the dataset and we will specify the inputs and outputs we will consider in our analysis, in Subsection 4.2 we will present the main results.

4.1. Dataset

The stylized supply chain in the power industry can be summarized in five main actors: gas and fuel suppliers, power generators, transmission networks, distribution facilities, and final users. Conventional power plants consume fuel oil, natural gas and diesel to produce electricity, while renewable ones are solar, wind and hydro plants. Conventional plants can be further divided depending on the kind of technology adopted, in thermal, gas and combined cycle plants. In general, thermal power plants operated by fossil fuels produce huge amounts of air pollutants. The pollutants which have been considered in the study are sulfur oxides (SO_X), nitrogen oxides (NO_X) and carbon dioxide (CO_2).

Our purpose is to highlight the theoretical and practical quality of the model, therefore each of the DMUs or the supply chain is built of five stages and each stage includes a set of partners connected to the predecessor stages members by some sustainable intermediate measures. In our application, we consider 10 supply chains (DMUs) including oil and gas fields (suppliers) that provide different fuels to power stations, power plants (manufacturers), regional power companies (transmitters), distribution companies (distributors) and customers. Per each supply chain, we consider two suppliers: oil and gas companies that satisfy the fuel demand of power plants (intermediate product) and that can also sell fuels as final output. Suppliers use one input (capital) under natural disposability and one input under managerial disposability (labor) and produce one desirable (oil or gas) and one undesirable output (flaring gas). The dual-role factor is considered as the cost of cleanup flare gas pollutions. Each manufacturer includes at least three power plants with different technologies (thermal, combined cycle, gas, hydro, wind and solar). They use fuels, capital and labor (under natural disposability) and labor of hydro power plant under managerial disposability to produce electricity and they sell it to regional power companies. To update and enlarge their capacity, manufacturers can substitute existing plants with more efficient ones or they can construct new plants. Three undesirable outputs are considered for manufacturers: CO_2, Nox and SO_X emissions. Also, we consider the dual-role factor as the Inner consumptions of power plants as technical and nontechnical consumptions. The transmitters transfer electricity from manufacturers to distributing companies and capacity and length of the lines are considered as inputs under natural disposability and the number employees of the department of programing and researches are used as input under managerial disposability. The dual-role factor is considered as specialist workforce in programming and researches. The loose in the transmission lines is considered as undesirable output while the construction of new lines is a desirable one. Distribution companies receive electricity from transmitters and dispatch them to the final consumers. They use two additional inputs capital estimated as capacity of the distribution lines and length of the distribution lines under natural disposability and the number of employees of engineering assistance department and programming as input under managerial disposability, one final desirable output as the meter of electricity and one undesirable output that is losses in the distribution lines. Finally, customers are classified as residential, agriculture, public and industrial. They use one input under natural disposability and one input under managerial disposability and produce two desirable outputs and one undesirable output. Table 1 indicates the production factors used for supply chain evaluation.

Table 1. Production factors in performance evaluation.

Division	Numerator	Factors	Definition
Supplier	h_s	$\overline{x}_{1j}^{h(s)}$	Capacity of oil (10^3 Barrels) and gas(10^6 m^3)
		$\tilde{x}_{1j}^{h(s)}$	Number of employees
		$g_{1j}^{h(s)}$	Oil (10^3 Barrels) and gas (10^6 m^3) sold
		$b_{1j}^{h(s)}$	Flaring gas of oil field (10^3 barrels)and gas field(10^6 m^3)
		$w_{1j}^{h(s)}$	Cost of flaring gas recovery
Manufacture	h_m	$\overline{x}_{1j}^{h(m)}$	Power nominal of power plants
		$\overline{x}_{2j}^{h(m)}$	Labor
		$\tilde{x}_{1j}^{h(m)}$	Labor of hydro plant
		$g_{1k}^{h_m}$	Percentage of new construction of power plant
		$b_{1k}^{h_m}$	Emissions of No_x harmful substances(10^3 Kg/10^6 Kwh)
		$b_{2k}^{h_m}$	Emissions of So_x harmful substances(10^3 Kg/10^6 Kwh).
		$b_{3k}^{h_m}$	Emission of Co_2 harmful substances(10^3 Kg/10^6 Kwh)
		$w_{1j}^{h(m)}$	Inner consumption of power plant
Transmitter	h_t	$\overline{x}_{1j}^{h(t)}$	Capacity of regional company (Mwa)
		$\overline{x}_{2j}^{h(t)}$	Length transmission line (Km circuit).
		$\tilde{x}_{1j}^{h(t)}$	Labor
		$g_{1k}^{h_t}$	New construction of transmission lines (Km)
		$w_{1j}^{h(t)}$	Number of employees
Distribution	h_d	$\overline{x}_{1j}^{h(d)}$	Capacity of distribution (Mwa)
		$\overline{x}_{2j}^{h(d)}$	Length transmission line (Km).
		$\tilde{x}_{1j}^{h(d)}$	Labor
		$g_{1k}^{h_d}$	New construction of distribution lines (Km).
		$b_{1k}^{h_d}$	Percentage of losses of distribution line (%).
Customer		$\overline{x}_{1j}^{h(c)}$	Average cost with fuel subsidy (Rial).
		$\tilde{x}_{1j}^{h(c)}$	Direct selling of electricity (10^6 Kwa).
		$g_{1k}^{h_c}$	Number of customer
		$g_{2k}^{h_c}$	Sales of electricity (10^6 Kwh)
		$b_{1k}^{h_t}$	Cut of power
		$v_{mk}^{(h,h')}$	Material flow from division h to division h' (10^6 Kwa)
		$z_{aj}^{(h_m,h_s)}$	Invers intermediate measures sent from manufactures divisions to supplier
		$z_{aj}^{(h_t,h_m)}$	Invers intermediate measures sent from transmitters to manufacture

More in detail, the parameters used to characterize this supply chain are defined as follows:
h_s : Numerator of divisions in the supplier level (h_s : 1, 2).
$\bar{x}_{1j}^{h(s)}$: Capacity of oil (10^3 Barrels) and gas (10^6 m^3) fields of h_s th supplier in jth supply chain.
$\tilde{x}_{1j}^{h(s)}$: Number of employees from h_s th supplier in jth supply chain.
$g_{1j}^{h(s)}$: Oil (10^3 Barrels) and gas (10^6 m^3) sold to other companies from the h_s th supplier in jth supply chain.
$b_{1j}^{h(s)}$: Flaring gas of oil field (10^3 barrels) and gas field (10^6m3) of the h_s th supplier in the jth supply chain.
$w_{1j}^{h(s)}$: The cost of cleanup of burned gas (flaring gas) of h_s th supplier in jth supply chain.
h_m : Numerator of division in the manufacturer level (h_m : 3, 4, 5).
$\bar{x}_{1j}^{h(m)}$: Power nominal of h_m th manufacturer in the jth supply chain (10^6 Kwh).
$\bar{x}_{2j}^{h(m)}$: Number of employees of h_m th manufacturer in the jth supply chain.
$\tilde{x}_{1j}^{h(m)}$: Number of hydropower employees of h_m th manufacturer in the jth supply chain.
$g_{1j}^{h(m)}$: Percentage of new construction of power plant of the h_m th manufacturer in the jth supply chain.
$b_{1j}^{h(m)}$: Emissions of Nox harmful substances of the h_m th manufacturer in the jth supply chain (10^3Kg/10^6Kwh).
$b_{2j}^{h(m)}$: Emissions of So_X harmful substance of the h_m th manufacturer in the jth supply chain (10^3Kg/10^6Kwh).
$b_{3j}^{h(m)}$: Emission of CO_2 harmful substance of the h_m th manufacturer in the jth supply chain (10^3 Kg/10^6 Kwh).
$w_{1j}^{h(m)}$: Inner consumption of power plants (technical and nontechnical consumptions) of the h_m th manufacturer in the jth supply chain (10^6 Kwh).
h_t : Numerator of the divisions the level of the transmitters (h_t : 6, 7).
$\bar{x}_{1j}^{h(t)}$: Capacity of transmission lines of the h_t th transmitter in the jth supply chain (Mwa).
$\bar{x}_{2j}^{h(t)}$: Length transmission line of the h_t th transmitter in the jth supply chain (Km circuit).
$\tilde{x}_{1j}^{h(t)}$: Number of employees department of programing and researches of the h_t th transmitter in the jth supply chain.
$g_{1j}^{h(t)}$: New construction of transmission lines of the h_t th transmitter in the jth supply chain (Km circuit).
$b_{1j}^{h(t)}$: Loose of transmission line of h_t th transmitter in the jth supply chain (%).
$w_{1j}^{h(t)}$: Number of employees of deputy transfer and exploitation of h_t th transmitter in the jth supply chain.
h_d : Numerator of division in the distributer level (h_d : 8, 9, 10, 11).
$\bar{x}_{1j}^{h(d)}$: Capacity of distribution lines of h_d th distributer in the jth supply chain (Mwa).
$\bar{x}_{2j}^{h(d)}$: Length distribution line of the h_d th distributer in the jth supply chain (Km).
$\tilde{x}_{1j}^{h(d)}$: Number of employees of engineering assistance department and programming of the h_d th distributer in the jth supply chain.
$g_{1j}^{h(d)}$: Meter of electricity of h_d th distributer in jth supply chain.

$b_{1j}^{h(d)}$: Percentage of losses of distribution line of h_d th distributer in the jth supply chain.
h_c : Numerator of division in the customer level (h_c : 12, 13, 14, 15).
$x_{1j}^{h(c)}$: Average cost with fuel subsidy of the h_c th customer in the jth supply chain (Rial).
$\tilde{x}_{1j}^{h(c)}$: Direct selling of electricity from transmitter Company to the h_c th customer in the jth supply chain (10^6 Kwh).
$g_{1j}^{h(c)}$: Number of customers of h_c th customer in the jth supply chain.
$g_{2j}^{h(c)}$: Sales of electricity of the h_c th customer in the jth supply chain (10^6 Kwh).
$b_{2j}^{h(c)}$: Cut off power of the h_c th customer in the jth supply chain (minute/year).
$v_{pj}^{(h,h')}$: Material flow from division h to division h' (10^6 Kwa).
$z_{aj}^{(h_m,h_s)}$: Power flow sent from power plants to oil and gas fields (10^6 Kwa).
$z_{aj}^{(h_t,h_m)}$: Labor sent from regional companies to power plants to repair and maintenance of systems.

The dataset has been collected from the power industry company in Iran and the reference year is 2015 (see TAVANIR website for the detailed data). The total emissions due to electricity generation in Iran, the amount and type fuel used in all power plants have been considered in the computation of undesirable outputs. All the data of the two oil and gas fields (suppliers), power plants (manufacturers), regional power companies (transmitters), distribution companies (distributors) and customers (residential, public, agriculture, industrial) are available in the TAVANIR website [30]. Supplier inputs are obtained from oil and gas fields statistics of the energy industry in Iran. The desirable output is computed as the difference between the average annual production and the amount of oil and gas that are sent to power plants; undesirable output (flaring gas) is calculated with a 0.03% rate of the annual production of oil and gas. Information related to the demanding fuel of power plants is collected from TAVANIR Company [30] in the power industry and they are considered as intermediate measures from oil and gas fields to power plants. The capacity of power plants is a proxy of the input capital. Undesirable outputs for manufacturers are computed based on the amount of electricity produced by the different power plants using different technologies and fuels. Dataset of inputs and desirable output of regional power company are collected from the transmission Division of TAVANIR Company in power industry and losses of the transmission line (undesirable output) are estimated with a 3.02% factor based on the amount of loose of transmission in Iran. All of the data of distribution company are obtained from dispatch division of TAVANIR company in power industry likewise input of customer divisions are collected from TAVANIR company and desirable output of customers are computed as total sale of electricity to residential, public, agriculture and industry divisions but undesirable output is computed by time cut off of electricity in different divisions of consumers in 2015 (see Pouralizadeh et al. [24]).

The data sets corresponding to the 10 supply chains (DMUs) under analysis are presented in Tables 2–17. Tables 2 and 3 shows inputs under natural and managerial disposability and desirable and undesirable outputs for suppliers 1 and 2. In Tables 4–7, we present the data of manufacturer (level 1, 2, 3). Tables 8 and 9 show the data of transmitters with two inputs under natural disposability and one input under managerial disposability, one good output and one undesirable output. Tables 10–13 collect the data on distributors where two inputs under natural disposability and, one input under managerial disposability, one desirable and one undesirable output are considered. Finally, in Tables 14–17 the data of customers are reported with one input under natural disposability and one input under managerial disposability, two desirable outputs and one undesirable output.

Table 2. The supplier level-inputs.

DMU	supplier 1 (division 1)		supplier 2 (division 2)	
	$\bar{x}^1_{1k}$	$\tilde{x}^1_{1k}$	$\bar{x}^2_{1k}$	$\tilde{x}^2_{1k}$
1	2550	3200	7200	2500
2	61200	1300	21600	2500
3	21600	3200	10800	2400
4	32400	3110	6480	1400
5	12600	2800	19440	3000
6	43200	2200	10800	2400
7	46800	2400	10800	1380
8	39600	1600	21600	2250
9	9360	2150	19440	2180
10	64800	2500	6480	2900

Source: category: oil field of iran-wikipedia, https//en.wikipedia.org/wiki/category:oil fields of iran; https//en.wikipedia.org/wiki/category:ntural gas in iran

Table 3. The supplier level desirable and undesirable outputs and dual-role factors.

DMU		Supplier1 (Division1)			Supplier2 (Division 2)	
	w^1_{1k}	g^1_{1k}	b^1_{1k}	w^2_{1k}	g^2_{1k}	b^2_{1k}
1	0.011	1739.693	54	4.725	1186.216	151.2
2	0.255	40572.996	1296	10.8	7203.230	345.6
3	0.085	8995.883	432	5.738	3726.203	183.6
4	0.191	26527.191	972	4.388	1930.025	140.4
5	0.042	4552.857	216	11.475	10438.190	367.2
6	0.149	23324.391	756	5.738	3350.675	183.6
7	0.149	17080.471	756	5.4	2353.130	172.8
8	0.127	15872.914	648	10.8	9455.104	345.6
9	0.038	6062.772	194.4	11.475	9849.593	367.2
10	0.255	25603.400	1296	4.388	2208.415	140.4
Calculation		Flaring gas and	Sold oil and	gas		

Table 4. Manufacturers level inputs.

DMU		Manufacturer1		Manufacturer 2		Manufacturer3			
	$\overline{x}_{1k}^{3}$	$\overline{x}_{2k}^{3}$	$\tilde{x}_{1k}^{3}$	$\overline{x}_{1k}^{4}$	$\overline{x}_{2k}^{4}$	$\tilde{x}_{1k}^{4}$	$\overline{x}_{1k}^{5}$	$\overline{x}_{2k}^{5}$	$\tilde{x}_{1k}^{5}$
1	63224	4070	610	15408	1600	5	11903	1200	0
2	16200	2263	27	10400	700	0	2626.952	2600	27
3	10448	1000	0	5701.12	3300	0	16760	2005	26
4	80224	1000	7	8622.4	3300	0	8344	2005	0
5	5184	890	0	1920.48	900	7	16417.760	2823	0
6	13672.88	2300	0	3312	2500	35	3936	800	0
7	966.32	1450	0	8352	2700	34	17844.8	890	0
8	1491.2	1520	21	10320	2260	9	16800	1300	0
9	3872	1500	0	10590	3600	17	7072	4100	106
10	11453.6	3180	40	6787.2	760	0	2053.28	1590	0

Source: http//amar.tavanir.org.ir//tolid and calculations million kilo watt hour

Table 5. Manufacturers level desirable and undesirable outputs and Dual-role factor.

DMU			Manufacturer 1 (Division 3)		
	w_{1k}^{3}	g_{1k}^{3}	b_{1k}^{3}	b_{2k}^{3}	b_{3k}^{3}
1	598.234	12.2	454610.278	23891876.280	288025420.100
2	92.234	12.2	302399.805	4207069.806	191952930.500
3	180.638	13	235104.740	195553.061	149621794
4	394.18	12.2	229464.218	12059407.75	145380628.200
5	10.78	73.6	43498.708	38755.471	27536231.770
6	25.768	100	256638.343	217529.667	163094448.800
7	2.939	85.5	6683.633	5954.829	4230977.926
8	81.863	85.5	15138.687	184259.151	9585079.623
9	42.59	13	92035.892	76552.691	58572086.910
10	139.981	86.6	236364.062	196600.528	150423232.700

Source: http//amar.tavanir.org.ir//tolid and calculations 1000kg/million kilo watt hour

Table 6. Manufacturers level desirable and undesirable outputs and Dual—role factor.

DMU			Manufacturer 2 (Division 4)		
	w_{1k}^{4}	g_{1k}^{4}	b_{1k}^{4}	b_{2k}^{4}	b_{3k}^{4}
1	0	85.5	5715.366	5092.145	3618030.390
2	541.271	0	283431.105	14895617.700	179572190
3	291.571	12.2	174773.192	9070013.802	110729096.200
4	86.474	25.2	182851.984	152090.788	116367887.400
5	96.326	12.2	49845.037	2619587.603	3158009.070
6	10.299	85.5	27420.014	24430.049	17357845.530
7	424.975	12.2	273496.466	14373506.370	173277944.500

Continued on next page

DMU		Manufacturer (Division 4)	2	
w_{1k}^{4}	g_{1k}^{4}	b_{1k}^{4}	b_{2k}^{4}	b_{3k}^{4}
8 0.063	12.2	311634.456	21776302.480	197440862.200
9 102.151	98.8	176752.534	147351.908	112467128.500
10 170.387	86.6	79593.197	66419.786	50641168.170

Source: http//amar.tavanir.org.ir//tolid and calculations 1000kg/million kilo watt hour

Table 7. Manufacturers level desirable and undesirable outputs and Dual—role factor.

DMU			Manufacturer 3 (Division 5)		
	w_{1k}^{5}	g_{1k}^{5}	b_{1k}^{5}	b_{2k}^{5}	b_{3k}^{5}
1	0	73.600	19603.894	17519.680	12447945.190
2	6.325	73.600	27423877.76	24433491.25	17360291475
3	103.532	98.800	212448.268	690393.877	135090771.800
4	92.426	13	140748.540	117070.408	89573051.780
5	47.29	87	300157.654	9178172.226	190308335.200
6	35.747	13	77463.980	64432.212	49298451.340
7	290.054	13	471751.939	21768344.370	299051808
8	782.679	13	510495.755	21776302.480	323709891.900
9	45.519	13	94829.614	78876.425	60350025.180
10	138.404	1.200	59895.401	3147780.793	37947663.670

Source: http//amar.tavanir.org.ir//tolid and calculations 1000kg/million kilo watt hour

Table 8. The Transmitter level inputs.

DMU	Transmitter 1 (division 6)			Transmitter 2 (division 7)		
	$\overline{x}_{1k}^{6}$	$\tilde{x}_{1k}^{6}$	$\overline{x}_{2k}^{6}$	$\overline{x}_{1k}^{7}$	$\tilde{x}_{1k}^{7}$	$\overline{x}_{2k}^{7}$
1	27542	74	8704	25086	39	14697.700
2	41011	78	9127.800	4938	17	2244.500
3	13659	38	8643.400	41011	78	9127.800
4	16545	25	10367.900	41011	78	9127.800
5	6871	26	2850.700	13659	38	8643.400
6	14068	42	11166.400	4938	17	2244.500
7	14171	51	5780.500	8762	26	4480.400
8	10812	33	8273.300	15407	23	6095.800
9	25086	39	14697.700	7367	35	3776.100
10	10812	33	8273.300	7716.4	22	1453.800

Source: http//amar.tavanir.org.ir//entaghl

Table 9. Transmitter level desirable and undesirable outputs and Dual—role factor.

DMU	Transmitter 1 (division 6)			Transmitter 2 (division 7)		
	w_{1k}^{6}	g_{1k}^{6}	b_{1k}^{7}	w_{1k}^{7}	g_{1k}^{7}	b_{1k}^{7}
1	1592	990	508.845	868	1541.4	51.880
2	115	1302.3	200.566	183	110	301.829
3	729	1961.5	175.381	1155	1302.3	357.789
4	566	1596	328.197	1155	1302.3	117.468
5	330	324	67.759	729	1961.5	263.987
6	559	431.3	254.862	183	110	107.780
7	615	1576.2	447.605	330	747	61.919
8	88	601.2	373.774	479	386	202.020
9	868	1541.2	273.358	231	110	84.462
10	88	601.2	294.146	426	1453.8	38.828

Source: http//amar.tavanir.org.ir//entaghal and calculations loose of electricity

Table 10. The distributor level inputs.

DMU	Distributor 1 (division 8)			Distributor 2 (division 9)		
	$\bar{x}_{1k}^{8}$	$\tilde{x}_{1k}^{8}$	$\bar{x}_{2k}^{8}$	$\bar{x}_{1k}^{9}$	$\tilde{x}_{1k}^{9}$	$\bar{x}_{2k}^{9}$
1	7792	47	40437	4067	54	60332
2	11349	292	64702	2330	61	19739
3	11349	292	64702	3068	79	28043
4	8612	55	12406	1787	42	8942
5	900	36	13383	2480	122	26770
6	11349	292	64702	3175	29	15731
7	3639	109	37153	1444	115	13785
8	2084	30	51688	4221	69	24689
9	7792	47	40437	1894	71	18162
10	2690	26	35606	2084	30	51688

Source: http//amar.tavanir.org.ir//tozee

Table 11. The distributor level inputs.

DMU	Distributor 3 (division 10)			Distributor 4 (division 11)		
	$\bar{x}_{1k}^{10}$	$\tilde{x}_{1k}^{10}$	$\bar{x}_{2k}^{10}$	$\bar{x}_{1k}^{11}$	$\tilde{x}_{1k}^{11}$	$\bar{x}_{2k}^{11}$
1	3325	36	13761	4492	58	10052
2	1787	42	18122	1324	19	11101
3	3651	115	32533	900	36	13383
4	1874	38	12075	3175	47	56184
5	3965	115	32533	3068	79	28043
6	1324	19	11101	1894	71	18162
7	900	36	13383	11349	292	64702
8	4067	54	60332	5395	65	52340
9	3325	36	13761	4067	54	60332
10	4067	54	60332	5395	65	52340

Source: http//amar.tavanir.org.ir//tozee

Table 12. Distributor level desirable and undesirable outputs.

DMU	Distributor 1 (Division 8)		Distributor 2 (Division 9)	
	g_{1k}^{8}	b_{1k}^{8}	g_{1k}^{9}	b_{1k}^{9}
1	576253	14.210	576253	8.030
2	2046151	7.200	323920	10.400
3	2046151	15.570	631924	11.390
4	1288350	15.570	345484	10.730
5	265678	13.250	662102	12.670
6	2046151	15.57	513660	11.510
7	497281	13.600	429044	11.050
8	294579	11.230	368658	13.330
9	576253	14.210	513660	7.250
10	469733	12.540	347768	11.230

Source:http//amar.tavanir.org.ir//tozee

Table 13. Distributor level desirable and undesirable outputs.

DMU	Distributor 3 (Division 10)		Distributor 4 (Division 11)	
	g_{1k}^{10}	b_{1k}^{10}	g_{1k}^{11}	b_{1k}^{11}
1	248079	13.590	327034	14.200
2	345484	10.730	208346	7.990
3	429044	11.050	265678	13.250
4	329071	7.670	309704	12.030
5	429044	11.05	631924	11.390
6	208346	7.990	333449	7.250
7	265678	13.25	2046151	15.570
8	550244	8.030	691491	8.100
9	208346	13.590	631924	8.030
10	550244	8.030	691491	8.100

Source: http//amar.tavanir.org.ir//tozee

Table 14. The customer level inputs.

DMU	Customer 1 (Division 12)	Customer 2 (Division 13)	Customer 3 (Division 14	Customer 4 (Division 15)
	$\bar{x}_{1k}^{12}$	$\bar{x}_{1k}^{13}$	$\bar{x}_{1k}^{14}$	$\bar{x}_{1k}^{15}$
1	1400	1094.800	1096.400	2802.500
2	1400	1094.800	1096.800	2802.500
3	1400	1094.800	1096.800	2802.500
4	1400	1094.800	1096.800	2802.500
5	1400	1094.800	1096.800	2802.500

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DMU	Customer 1 (Division 12) $\bar{x}_{1k}^{12}$	Customer 2 (Division 13) $\bar{x}_{1k}^{13}$	Customer 3 (Division 14 $\bar{x}_{1k}^{14}$	Customer 4 (Division 15) $\bar{x}_{1k}^{15}$
6	1400	1094.800	1096.800	2802.500
7	1400	1094.800	1096.800	2802.500
8	1400	1094.800	1096.800	2802.500
9	1400	1094.800	1096.800	2802.500
10	1400	1094.800	1096.800	2802.500

Source: http//amar.tavanir.org.ir//tozee

Table 15. The customer level inputs under managerial disposability.

DMU	Customer1 (Division 12) $\tilde{x}_{1k}^{12}$	Customer2 (Division 13) $\tilde{x}_{1k}^{13}$	Customer 3 (Division 14 $\tilde{x}_{1k}^{14}$	Customer 4 (Division15) $\tilde{x}_{1k}^{15}$
1	0.000	258.173	30.0710	7195.787
2	0.000	4.89300	28.7950	68.90600
3	0.000	38.7860	22.8310	3564.162
4	0.000	4.89300	74.6070	6801.258
5	0.000	0.00000	17.8910	2024.679
6	0.000	0.00000	310.5440	2241.095
7	0.000	0.00000	0000.000	1276.555
8	0.000	112.4370	0000.000	6377.373
9	0.000	258.1730	0000.000	4747.578
10	0.000	61.16200	141.2120	218.9860

Source: http//amar.tavanir.org.ir//tozee

Table 16. The Customer level desirable and undesirable outputs.

DMU	Customer 1 (division 12)			Customer 2 (division 13)		
	g_{1k}^{12}	g_{2k}^{12}	b_{1k}^{12}	g_{1k}^{13}	g_{2k}^{13}	b_{2k}^{13}
1	1830958	6122.147	778.277	347030	3241.136	147.510
2	6441756	5485.296	725.081	1778416	2903.980	200.178
3	7866277	5821.292	725.323	2168359	3081.860	199.937
4	6560395	4865.888	727.327	1791210	2576.059	198.585
5	3804176	3622.099	752.559	855850	1917.582	169.308
6	8009286	3996.064	734.466	2078242	2115.563	190.588
7	8271676	5563.775	693.427	2196721	2945.528	184.154
8	3602333	6217.991	718.110	962150	3291.877	191.801
9	3213868	3906.777	752.079	691239	2068.293	161.757
10	3683518	3635.504	722.771	953080	1924.679	187.011

Source: http//amar.tavanir.org.ir//tozee and calculations time cut off of electricity

Table 17. The Customer level desirable and undesirable outputs.

DMU	Customer 3 (division 14)			Customer 4 (division 15)		
	g_{1k}^{14}	g_{2k}^{14}	b_{1k}^{14}	g_{1k}^{15}	g_{2k}^{15}	b_{1k}^{15}
1	16364	2700.947	6.956	7663	5942.083	3.257
2	37745	2419.983	4.249	57685	5323.964	6.492
3	51444	2568.217	4.743	65030	5650.077	5.996
4	37480	2146.715	4.155	53509	4722.774	5.932
5	42460	1597.985	8.400	28981	3515.567	5.733
6	45458	1762.970	4.169	73999	3878.533	6.786
7	624532	2454.607	52.355	72330	5400.135	6.064
8	106646	2743.231	21.259	24231	6035.109	4.830
9	54540	1723.578	15.103	30174	3791.871	7.061
10	110055	1603.899	21.595	23562	3528.578	4.623

Source: http//amar.tavanir.org.ir//tozee and calculations time cut off of electricity

The material flow or intermediate measures from suppliers divisions to manufacturers divisions, from manufactures divisions to the transmitters divisions and from transmitters divisions to distributors divisions and from them to the customers divisions are presented in appendix Tables 18–23. Tables 24 and 25 of Appendix indicates inverse intermediate measures to exit from manufactures divisions and enter to suppliers divisions, exit from transmitters divisions and enter manufactures divisions. The division's weights and the overall weights of the 15 divisions are presented in Table 26.

4.2. Results

We now describe the results obtained in the new proposed approach. The model (10) is applied to estimate the efficiency score of supply chain 10 (DMUS). The model(10) is solved by a linear programming solver using the GAMS software on a 8GB RAM, 2.0 GHz desktop computer, the runtime of the computation in this study is negligible in model. The results are listed in Table 27.

Table 18. The inefficiency scores of supply chains (DMUs)

DMU	θ_o	ξ_k^{S1}	ξ_k^{S2}	ξ_k^{M2}	ξ_k^{M2}	ξ_k^{M3}	ξ_k^{T1}	ξ_k^{T2}	ξ_k^{D1}	ξ_k^{D2}	ξ_k^{D3}	ξ_k^{D4}	ξ_k^{C1}	ξ_k^{C2}	ξ_k^{C3}	ξ_k^{C4}
1	0.005	0	0	0	0	0	0	0	0.006	0	0.16	0	0	0	0	0
2	0.13	0	0	0	0	0	0.42	0	0	0.25	0.22	0	0.33	0	0.15	0.30
3	0.20	0	0.41	0	0	0.92	0	0	0	0.50	0.19	0	0.36	0	0.28	0.36
4	0.16	0	0	0	0	0.47	0.56	0	0	0	0.36	0	0.23	0	0.09	0.23
5	0.10	0	0	0	0	0.63	0	0	0	0.58	0.19	0.58	0	0	0	0
6	0.05	0	0.35	0	0	0	0	0	0	0	0	0.33	0	0	0.08	0
7	0.15	0	0.21	0	0	0	0	0.4	0	0.6	0	0	0.32	0.32	0	0.32
8	0.09	0	0	0	0	0	0	0	0	0	0	0.56	0.24	0	0	0.22
9	0.04	0	0	0	0	0	0	0	0	0.58	0	0	0	0	0	0
10	0.03	0	0	0	0	0	0	0	0.28	0	0	0.56	0	0	0	0

The first column of Table 18 represents the global inefficiency score of the supply chains. It can be easily seen that no DMU can reach inefficiency equal to null. This implies that all the 10 supply chains can improve their performance in some of the divisions. Supply chain number 1 is the one that reaches the lowest inefficiency score (0.005) while supply chain number 3 is the worst performing one. Looking vertically in the tables, the more efficient divisions are divisions 1, 3, 4 and with efficient values (100% of the total). This implies that supplier 1, manufacturers 2 and 3 are the more efficient ones concerning the other divisions. Just one efficient unit (90%) is obtained in the case of divisions 7 (Transmitter 2).

As an illustration, we consider the four divisions of residential, public, agriculture and industrial from power consumers to identify DTR measures and effective investment on customer divisions in supply chains 10 of the power industry. This study applies the proposed radial model to examine the sustainability performance of supply chains. In the first stage, the supply chain management enables according to the dual variables sign related to desirable output constraints determent if the investment to new technology innovation decrease undesirable output or no then in the next stage, if the dual variables sign was negative then the decision-maker define the type input under management disposability from customer divisions in supply chain as their increase has an effective or limited effect to abatement of undesirable outputs. In other word, if the dual variable sign is positive then the investment does not effective to decrease of undesirable outputs. Tables 19-22 indicate the dual variables of the optimal solution of model (11) related to inputs under natural and managerial disposability and desirable outputs in residential, public, agriculture and industrial divisions of power subscribers on electricity companies 10 in different regions of Iran.

Table 19. The dual variables of inputs and undesirable output of residential division.

DMU	Dual variable of inputs under Natural disposability v	Dual variable of inputs under Managerial disposability z	Dual variable of desirable output U1	Dual variable of desirable output U2	DTR	Effective of investment
1	0.00000162	0.00000162	0.000000044239	0.00000000	P	--
2	0.00000162	0.00000162	−0.000000001466	0.000016489	N	E
3	0.00000162	0.00000162	−0.000000001407	0.000015815	N	E
4	0.00000162	0.00000162	−0.000000001682	0.000018914	N	E
5	0.00000162	0.00000162	0.0000000022301	0.0000020021	P	--
6	0.00000162	0.00000162	−0.000000002194	0.00000024667	N	E
7	0.00000162	0.00000162	−0.000000001492	0.00000016777	N	E
8	0.00000162	0.00000162	0.00000001082	0.00000067567	P	--
9	0.00000162	0.00000162	0.00000001432	0.00000089453	P	--
10	0.00000162	0.00000162	0.000000008172	0.0000014056	P	--

Table 20. The dual variables of inputs and undesirable output of public division.

DMU	Dual variable of inputs under Natural disposability	Dual variable of inputs under Managerial disposability	Dual variable of desirable output	Dual variable of desirable output		Effective of investment
	v	z	U1	U2	DTR	
1	0.0000018	0.0000000055	0.0000002074	0.00000000	P	--
2	0.0000018	0.0000000055	0.00000002155	0.00001159	P	--
3	0.0000018	0.0000255	−0.00000001251	0.00003216	N	E
4	0.0000018	0.0000000055	0.00000003009	0.000024116	P	--
5	0.0000018	0.0000000055	0.00000003009	0.000024116	P	--
6	0.0000018	0.0000000055	−0.00000006928	0.00004084	N	E
7	0.0000018	0.0000000055	−0.00000004747	0.000027984	N	L
8	0.0000018	0.0000000055	0.0000065392	0.0000027592	P	--
9	0.0000018	0.0000000055	0.0000055462	0.000016276	P	--
10	0.0000018	0.000001523	0.00000007132	0.00003387	P	--

According to Table 19, $u_1^* < 0$ for supply chains number (2, 3, 4, 6, 7) of residential division and they belonged to negative DRT, so indicating technology innovation was essentially necessary for enhancing their efficiency and sustainability. Moreover, the amount of the dual variable of input under managerial disposability determines the type of investment on inputs. Other word, $z^* > W\varepsilon R_q^x$ for supply chains number (2, 3, 4, 6, 7) then input for investment under managerial disposability can effectively decrease the number of undesirable outputs and is rated as E (Effective investment). Therefore, they have a high potential for an investment opportunity to enhance the entire supply chain sustainability. Similarity, supply chains number (1, 5, 8, 9, 10) belonged to positive DTR so indicating that the technological innovation was not an essential necessary for increase their unified efficiency and sustainability improvements in performance assessment.

Similarity, according to Table 20 supply chains number (3, 6, 7) of public division of power customer have $u_1^* < 0$ hence negative Damage to return (N) occurs on division public of supply chains so this case indicate technology innovation was essentially necessary for enhancing their efficiency and sustainability. In other word, the amount $z_1^* > W\varepsilon R_1^x$ for supply chains number (3, 6) hence input for investment under managerial disposability can effectively decrease the number of undesirable outputs and is rated as E (Effective investment). Similarity, supply chains number 7 belonged to negative DTR and $z^* = W\varepsilon R_q^x$ so the input for investment under managerial disposability has a limited effect on decrease some of undesirable outputs because z^* is a very small positive number so the investment has only a limited effect and it rated as L (limited investment). Finally, supply chains number (1, 2, 4, 5, 8, 9, 10) belonged to positive damage to return (P) so indicating that the technological innovation was not an essential necessary for increasing their unified Efficiency in performance assessment.

Table 21. The dual variables of inputs and undesirable output of agriculture division.

DMU	Dual variable of inputs under Natural disposability v	Dual variable of inputs under Managerial disposability z	Dual variable of desirable output U1	Dual variable of desirable output U2	DTR	Effective of investment
1	0.0000015	0.0000000038642	0.0000036666	0.0000000	P	--
2	0.0000015	0.00014888	0.00000062738	0.000001500	P	--
3	0.0000015	0.000012614	0.0000005315	0.0000012715	P	--
4	0.0000015	0.000016028	0.0000006742	0.0000016157	P	--
5	0.0000015	0.000000074749	0.000017686	0.0000017686	P	--
6	0.0000015	0.00013692	0.0000013199	0.0000000000	P	--
7	0.0000015	0.00000003842	−0.00000006977	0.000042196	N	L
8	0.0000015	0.000000038642	0.00000065261	0.000000000	P	--
9	0.0000015	0.00000003760	0.00000061798	0.000011671	P	--
10	0.0000015	0.000084827	0.00000054518	0.000000000	P	--

According to Table 21 supply chains number 7 of agriculture division have $u_1^* < 0$ and belonged to negative DRT and $z_1^* = W\varepsilon R_1^x$ then the input under managerial disposability for investment has a limited effect on decrease some of undesirable outputs and it rated as L (limited investment) and the other supply chains belonged to positive DTR so indicating that the technology innovation was not an essential necessary for increasing their unified Efficiency.

Table 22. The dual variables of inputs and undesirable output of industrial division.

DMU	Dual variable of inputs under Natural disposability v	Dual variable of inputs under Managerial disposability z	Dual variable of desirable output U1	Dual variable of desirable output U2	DTR	Effective of investment
1	0.00002017	0.00000000024	0.000011353	0.0000000	P	--
2	0.00002017	0.00000000024	−0.000000055	0.00001694	N	L
3	0.00002017	0.000016557	−0.00000001281	0.000016872	N	E
4	0.00002017	0.000010272	0.0000003085	0.000014925	P	--
5	0.00002017	0.000002201	0.000000777	0.00001833	P	--
6	0.00002017	0.00000000024	−0.0000002137	0.000026509	N	L
7	0.00002017	0.00000000024	−0.0000001456	0.000018061	N	L
8	0.00002017	0.00032940	0.000015013	−0.00004586	N	E
9	0.00002017	0.0000024261	0.0000010953	0.000014228	P	--
10	0.00002017	0.0000000002	0.0000018587	0.000012245	P	--

Finally, according to Table 22 supply chains number (2, 3, 6, 7) of industrial division have $u_1^* < 0$ and supply chain number 8 has $u_2^* < 0$ and negative DRT, so indicating technology innovation was essentially necessary for enhancing their efficiency and sustainability. In other words, the amount $z^* > W\varepsilon R_q^x$ for supply chains number 3 and 8 hence the input for investment under managerial disposability can effectively decrease the number of undesirable outputs and is rated as E (Effective investment). Therefore, they have a high potential for an investment opportunity to enhance the entire supply chain sustainability. Similarity, supply chains numbers (2, 6, 7) belonged to negative DTR and $z^* = W\varepsilon R_q^x$ therefore, input for investment has a limited effect on decrease a number of undesirable outputs and it rated as L (limited investment). Finally, supply chains number (1, 4, 5, 9, 10) belonged to positive DTR so technological innovation was not an essential necessary for increase their unified efficiency and sustainability improvements in performance assessment.

Table 23 summarizes effective and limited investment opportunity on ten supply chains of four division of consumers in the power industry, all of them are specified by DTR and they are classified into two investment categories (effective and limited investment).

Table 23. Effective and limited investment opportunity on supply chain 10 in the power.

	Effective investment	Percent %	Limited investment	Percent %
Residential	5	0.5	0	0.0
Public	2	0.2	1	0.10
Agriculture	0	0.1	1	0.10
Industrial	5	0.5	3	0.30

As summarized in the Table 23 the industrial division of the power consumers had depicted a high level of effective (0.50) and limited investment (0.30) opportunity. Therefore, the industrial sector may have a high potential for an investment opportunity to enhance the entire sustainability. Finally, it is worth noting the energy and industrial sectors are the most attractive investment regions for enhancing sustainability and efficiency in production processes.

5. Conclusions

The electricity supply chain is a network of energy sectors, power production divisions, transmission and distribution lines, and power subscribers. The power industry is one of the important investment targets for reducing wasted energy in oil and gas fields and power plant sectors and enhancing corporate sustainability. Furthermore, the investment to decrease the power losses in transmitter and distributer lines is an immediately necessary to increasing operational and environmental efficiency. This study proposes a model radial to a supply chain sustainability assessment which measures an investment opportunity for technology innovation and decreasing the number of undesirable outputs in the different sectors of the supply chain. Also, technology innovation in the energy and industrial sectors not only prevents energy losses but also abatement global warming and climate changes. It is immediately necessary to know whether the investment to undesirable outputs abatement can effectively decrease a number of undesirable outputs or increase the inputs under managerial disposability have a limited effect on decrease a number of undesirable outputs. In other words, an important feature of the proposed approach is that it able to identify the investment on which division of supply chain has a major or minor impact in decrease a number of undesirable outputs. Besides, it is possible to increase an input under managerial disposability may be ineffective in undesirable produces reduction.

This study has two empirical results of customer divisions. One of the two results is that the transmission and distribution companies must have adequate decisional capacities regarding investment for transmitting directly the power to industrial, agriculture divisions and sectors of high electricity consumption in the power industry. Particular, the residential and industrial divisions have significant capacities on investment and technology innovation for reducing undesirable outputs to achieve corporate sustainability in the supply chain. The other result is that the dual-role factors have an important key role in the handling of undesirable output in the energy sector and the abatement inner the electricity consumptions of power plants in electricity production sector and managing specialist workforce to decrease of losses power in transmitter lines. Moreover, they able to enhance the effectiveness of transmission and distribution lines in the network supply chain. In general, all of the studied researches about environmental performance assessment of supply chain do not consider network DEA model based on investment to new technology innovation and undesirable products reduction. Also, the proposed model is able to handling investment on capital assets to the pollution emissions abatement and the power losses in the electricity supply chain divisions. Indeed, the difference between the proposed model and other approaches is that the model is able to recognize increase which the categories inputs cause significant decrease in wasted energy and harmful emissions. The proposed approach has three methodological limitations in leading environmental performance assessment. First, the source energy is different among districts. Each region has its essential structure and different conditions for business activity. For instance, southern regions in Iran have noticeable energy sources and the high capacity of power plants respect to other regions. Such regional difference effects on the number of efficiency measures in each regional. Second, the proposed approach assumes that all unified efficiency measures are uniquely determined on optimality. If the uniqueness assumption of efficiency measures is dropped, the proposed model needs to incorporate strong complementary slackness conditions into the model to obtain a unique optimal solution. The assumption on uniqueness is appropriate to the measurement of the dual variable by the model (11). Third, this study has not considered many companies in the proposed DEA assessment that contain a negative value on production indexes. The problem considered in this study needs to further researches in future. Similarity, this study can be conducted for green supply chain management evaluation in a time horizon by Malmquist index computation on time-series data to examine the frontier shift among multiple periods.

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Conflict of interest

There is no conflict of interest in this paper.

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