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*Research article*

# Supply chain performance evaluation in the presence of undesirable products: A case on power industry

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**Abstract:** One of the most serious problems in electricity supply chain management is excessive energy consumption in oil and gas fields and power plant sections and the control wasted energy or power losses in transmission and distribution lines. The resource allocation and utilization to environmental preservation of pollution gas emissions play a fundamental role in the implementation progress of energy and power plant sections and transmission and distribution lines in the power industry. In fact, the purpose of this study is to examine the effects of activity level control to flare gas reduction and environmental protection in energy and power plant sections and power losses management in an electricity supply chain. In other words, this study proposes a DEA model for evaluating electricity supply chain management to sustainability and environmental preservation in economic activity. A real case on the Iran power industry is presented to demonstrate the applicability and practicability of the proposed method. To demonstrate the capability of the proposed approach, this framework is implemented for the performance evaluation of a supply chain identified by oil and gas companies, power plants, transmissions companies, dispatching companies and final consumers in Iran. One empirical implication has obtained from the model performance. As the results show approximately, power plants have earned efficient more than 80% of the total in supply chains but oil and gas fields need to make their efforts to reduce pollution substance emissions by flare gas recovery and putting out oil fields burners. Also, the results demonstrate excessive wasted energy in the transmission and distribution lines as they need to engineer workforce to power loses abatement. Besides, this study recommends that the energy, power plant, transmission and distribution networks should be equipped with improved engineering systems and specialist workforce to economic boom increase and energy losses abatement and environment preservation from industrial pollutions.

**Keywords:** sustainability; weak disposability; supply chain; performance evaluation

## 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. Supply chain management includes a set of profit methods to the efficient and effective integration of supplier, manufacturer, transmitter, distribution, and customer to minimize of system costs and prompt and reliable delivery of high-quality products. The energy sector is considered one of the most important types of advanced infrastructures in any country. The oil and gas fields and refineries are considered as the energy basic sectors in Iran so they provide demand fuels to nonrenewable power plants. More than 150 billion cubic meters flare gas released in the world, annually. According to the World Bank statistics in the year 2017, this number is equivalent to one-third of Europe continent consumption that seventy-five percent of emitted gases belong to ten countries as Iran had a global third rank and first rank in the Middle East. Also, Energy and power plant sections besides to produce energy, consume a lot of energy in economic activities. For instance, the daily more than 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. Therefore, the flare gas recovery and return of wasted energy to gas natural cycle are an immediately necessary to environmental efficiency enhancement and economic growth. Similarity, power plants from production to consumption produce various harmful substances in the environment. Power plants are the largest fossil fuel consumers such as coal, fuel oil and gasoline and natural gas. These fuels play most of the role in electricity production Therefore, the more usage of them and power production increases greenhouse gas emissions. In the global scale, the key greenhouse gases are carbon dioxide ($CO_2$), methane ($CH_4$), nitrogen oxides, and sulfur oxides. These gases have been released during the combustion of fossil fuels also Electricity production generates the largest share of greenhouse gas emissions. Approximately, 68 percent of consumption electricity comes from burning fossil fuels, mostly coal, fuel oil, gasoline and natural gas. Carbon dioxide ($CO_2$) 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 an 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. In this case, decision-makers should adapt to various regulations to reducing pollution emissions. 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 kilo watt-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 word, if supply chain enterprises equipped with improved engineering capability and invest in improvement and repair of equipment in all of the divisions then undesirable outputs considerably decrease in production processes. Besides, the resulting investment in the energy industry, power plant sections and transmission and distribution lines usually depend on the especial span time for fulfillment and enterprise improvement. Therefore, supply chain management should can propose an appropriate approach to activity level control and wasted energy harness to environmental efficiency enhancement in the power industry. Data envelopment analysis (DEA) is a profitable method for performance of new ideas to the protection of environmental harmful effects in industrial activity. Let us now suppose that supply chain divisions apply inputs to produce desirable and undesirable outputs and the material flow is transferred from suppliers to manufacturers and from manufacturer to transmitters and from them to distributors and finally from distributors to customers in the production processes. Let us consider undesirable outputs such as emissions of harmful substances in the air, water and ground and other detrimental variables of production activities.

In this study, we are going to answer the following question: how a decision-making unit or a supply chain enables decrease pollution gases emissions in oil and gas fields and power plants by scale down of production level and power plants fuel consumptions regulation and nominal capacity handling as power losses dramatically decrease in transmission and distribution lines ? In this case, decision-makers should be able to identify which inputs of supply chain divisions decline to wasted energy abatement in electricity supply chain sectors. Indeed, the supply chain management needs to the size and type of reduced inputs 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.

Therefore, supply chain management enables simultaneously minimize the negative environmental impacts whilst maximizing its operational performance Indeed, the main objective of supply chain management is minimizing operational and environmental costs while delivering value products to customers by production, transmission, and distribution inaccurate quantity, to suitable place, at the correct time and in a sustainability process. In other words, to achieve this goal we may compare cases in which firms are usually interested in decreasing inputs and undesirable outputs. Now we consider the week disposability of undesirable outputs. In addition, the weak disposability is accomplished by the activity level control to flare gas recovery and environmental protection into energy sections also the week disposability assumption is adapted to the inner electricity consumption control of power plants (technical and non-technical) and prevention of pollution gases emissions in power plants sectors. Similarity, the weak disposability is employed to the capacity and length control of transmission and distribution lines and power losses reduction in transmission and distribution networks.

To include the undesirable outputs in the technology and account for their negative impact on productivity Hailu et al. [1] introduced disposability conditions on their technology which they refer to as the "weakly disposable" and treated detrimental variables as inputs, Färe et al. [2,3] applied an alternative approach that models undesirable emissions as outputs and imposing an assumption that these undesirable outputs are weakly disposable. They implicitly assume that all firms in the sample application a uniform abatement factor. Kuosmanen [4] presented a simple formulation of weak disposability that allows for non-uniform abatement factors and preserves the linear structure of the model.

In this paper, we introduce a DEA approach to calculate environmental and operational efficiency in an electricity supply chain. Furthermore, DEA can conduct an industrial policy regarding how to increase the level of economic prosperity and how to decrease the amount of flare, GH gases and power losses, simultaneously. In the offered model the intensity weights of supply chain divisions separated into two categories of components as one of two category components related to the amount outputs are abated through scaling down of activity level and the other category contains components that remains active in the production process. In other word, this study focuses on environmental assessment of supply chain that minimizes the environmental impacts and maximizes economic returns and satisfies social requests. Besides, the supply chain sustainability assessment is measured by its divisions' efficiency scores that the first priority is environmental performance and the second priority is operational performance.

The rest of the paper is organized as follows. In Section 2, we present a review of the appropriate literature in DEA and supply chain management that indicates weak disposability in nonparametric production analysis with undesirable outputs. In Section 3, we present a brief review of the DEA model namely the "weakly disposable" DEA model. We show how to correctly specify weak disposability in an activity analysis model of supply chain performance evaluation problems. Section 4 is devoted to introducing a procedure to calculate unified efficiency (operational and environmental) of the supply chain under weak disposability of undesirable outputs and free disposability of inputs and desirable outputs. In Sections 5 we present a case study to exhibit properties of the procedure and demonstrate the applicability of the proposed method to a supply chain performance evaluation problem to the power industry in Iran. In Section 6 we present our conclusions.

## 2. Literature review

The undesirable factors may also need to be considered in real- life applications. In this section, various studies on undesirable outputs and green supply chain management GSCM are briefly summarized as follows.

Hailu et al. [1] extend the non-parametric analysis of Chavaz et al. [5] by incorporating undesirable outputs to provide a more complete representation of the production technology. Shephard [6] introduced the definition of weak disposability and proposed basic production axioms on that. They constructed Inner and outer non-parametric technology bounds. They also introduced disposability condition on their technology, which claimed as is preferable to what they referring to as the "weakly disposable" DEA model and developed a production model.

Färe et al. [4,5] showed that the monotonicity condition introduced by Hailu et al. [1] is inconsistent with physical laws and the standard axioms of production of weak disposability according to [3] and implicitly assume that, all firms in the sample application a uniform abatement factor. Kuosmanen [4] presented an alternative approach that models undesirable emissions as outputs imposing an assumption that these undesirable outputs are weakly disposable. He showed how weakly disposable technology can be modeled in a way such that non-uniform abatement factors can be applied as Kuosmanen technology is the correct minimum extrapolation technology under the stated axioms.

Data Envelopment Analysis (DEA) was developed by the CCR model [8] to evaluate the relative efficiency of decision-maker units (DMUs).To measure the efficiency of the complex network systems, Färe and Grosskopf [9] and Färe et al [10] built division production possibility set satisfying the standard available in [11].Tone and Tsutsui [12] proposed a method called Epsilon based measure (EBM). The EBM models simultaneously consider both the radial and non-radial measures of efficiency in DEA. Färe et al. [10] developed a sequence of network models. They presented three network models and formalized technologies by a series of linear in quality constraints.

Zhu [13] proposed a DEA approaches for airlines performance by two–stage network.

Kao et al. [14] built a relation network DEA model, taking into account the interrelationship of the processes within the system to measure the efficiency of the system and those of the processes at the same time.

Kao [15] modified the conventional DEA model by taking into account the series relationship of the two sub-processes within the whole process.

Tone and Tsutsi [16] proposed a slacks-based network DEA model called network SBM.

Chen and Yan [17] consider a general network structure in which modeling processes are based upon the concept of centralized, decentralized and mixed control organization mechanisms. They first build division production possibility set all satisfying the strong free disposability as it is common in conventional DEA models, then the production possibility set of the assumption supply chain is formed by combining its divisional production possibility sets. They calculated supply chain efficiency according to [18] projection on the efficient frontier of the supply chain.

Tavana et al. [19] extended the EBM model proposed by Tone and Tsutsi [16] and proposed a new Network EBM (NEMB).

Nevertheless, all of the above- mentioned approaches to determine efficiency score assume that the outputs are desirable.

Mirhedayatian et al. [20] presented a DEA-based model in the presence of undesirable outputs, dual-role factors, and fuzzy data. They indicated a method to improve environmental performance a green the supply chain management and incorporate dual-role factor and undesirable output into (NSBM) model proposed by Tone and Tsutsui [12].

Tajbakhsh et al. [21] 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.

In summary, all of the abovementioned references for environmental performance assessment of supply chain do not consider network DEA model based on production level reduction to undesirable products. Also, the aforementioned models are not able to define parameters to the amount activity level abatement and undesirable products.

## 3. The production technology set of overall supply chain and all of the divisions

In this Section is reported the production technology set and outputs set to the overall supply chain and its divisions under weak disposability of undesirable outputs.

### *3.1. Modeling weak disposability in a supply chain*

Definition: Outputs are weakly disposable if $(v, w) \in p(x)$ and $0 \le \theta \le 1$ implies $(\theta v, \theta w) \in p(x)$ (see[3]).

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, respectively. Also, $x_{nk}^h, y_{rk}^h, w_{jk}^h$ represent the nth input $(n = 1,...,N)$, the rth desirable output $(r = 1,...,s)$ and the jth undesirable output $(j = 1,...,J)$ of the $h$ th division $h = (1,...,H)$ in the kth supply chain $(k = 1,...,K)$, respectively. $v_{m\,k}^{(h,h')}$ Represents the intermediate measure between the $h$ th division to the $h'$ th division of kth supply chain (DMU) with subscript (m,k) indicating mth intermediate measure $(m = 1,...,M_h)$ in kth supply chain $(k = 1,...,K)$. Furthermore, $\theta_k^h$ are defined as abatement factors that scale down both desirable and undesirable outputs of $h$ th division in kth supply chain and $z_k^h$ indicate the intensity is divided into two parts as $z_k^h = \lambda_k^h + \mu_k^h$ where $\mu_k^h$ represents the part of output that is abated through scaling down of activity level and $\lambda_k^h$ denotes the part of output that remains active of $h$ th division in kth supply chain ( $\lambda_k^h = \theta_k^h z_k^h$ ). $s_{mk}^{(h_s,h_m)} s_{mk}^{(h_m,h_t)}, s_{mk}^{(h_t,h_d)}, s_{mk}^{(h_d,h_c)}$ represent slack variables of mth intermediate measure 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 in kth supply chain (k=1,…,K). $\phi_{h_s}, \phi_{h_m}, \phi_{h_t}, \phi_{h_d}, \phi_{h_c}$ Represent the reduction variables of all undesirable outputs in suppliers, manufacturers, transmitter, distributors and customers divisions, respectively Suppose we observe the production data of k supply chains; the data for supply chain $(k = 1,...,K)$ and hth division $(h = 1,...,H)$ are represented by the vector, $\left(v_k^h, y_k^h, w_k^h, x_k^h\right)$. The production technology set of hth division in the kth supply chain is defined as follows. $Y = \left\{\left(v_k^h, y_k^h, w_k^h, x_k^h\right) \middle| \; x_k^h \; can\ produce \left(v_k^h, y_k^h, w_k^h\right)\right\}$ Thus, the outputs set of hth division in the kth supply chain can be indicated as follows: $P_k^h(x) = \{(v_k^h, y_k^h, w_k^h) \mid (v_k^h, y_k^h, w_k^h, x_k^h) \in Y\}$

*3.2. The production technology set of overall supply chain and all of the divisions*

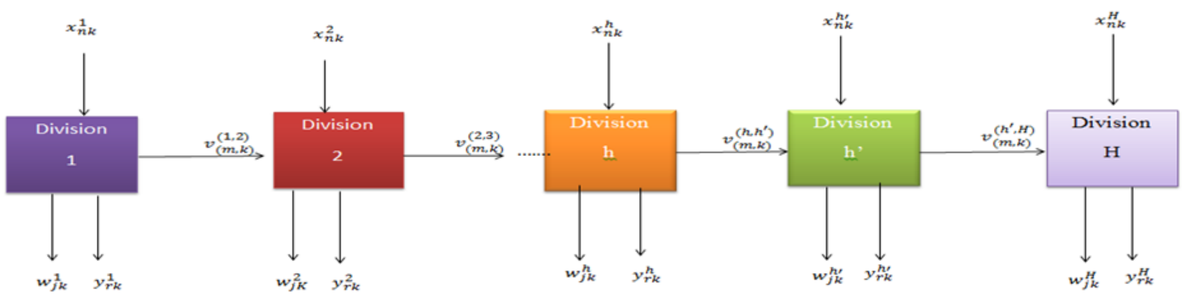


**Figure 1.** The general structure of supply chain.

Let us consider the general structure of the supply chain depicts in Figure 1.

We shall assume free disposability of inputs and good outputs, weak disposability of good and undesirable outputs, the convexity of Y and variable returns to scale. In this method, the parameters abovementioned and intermediate measures are incorporated into the network model to the performance evaluation of cooperative and non-cooperative network and slack variables of intermediate measures are unrestricted that they will recognize better activity level as the decline in desirable output. Furthermore, the experimental outputs set are considered to suppliers, manufacturers, transmitter distributions and division's customer and they indicate as, $P_s(x), P_m(x), P_t\ (x), P_d\ (x), P_c\ (x)$, respectively.

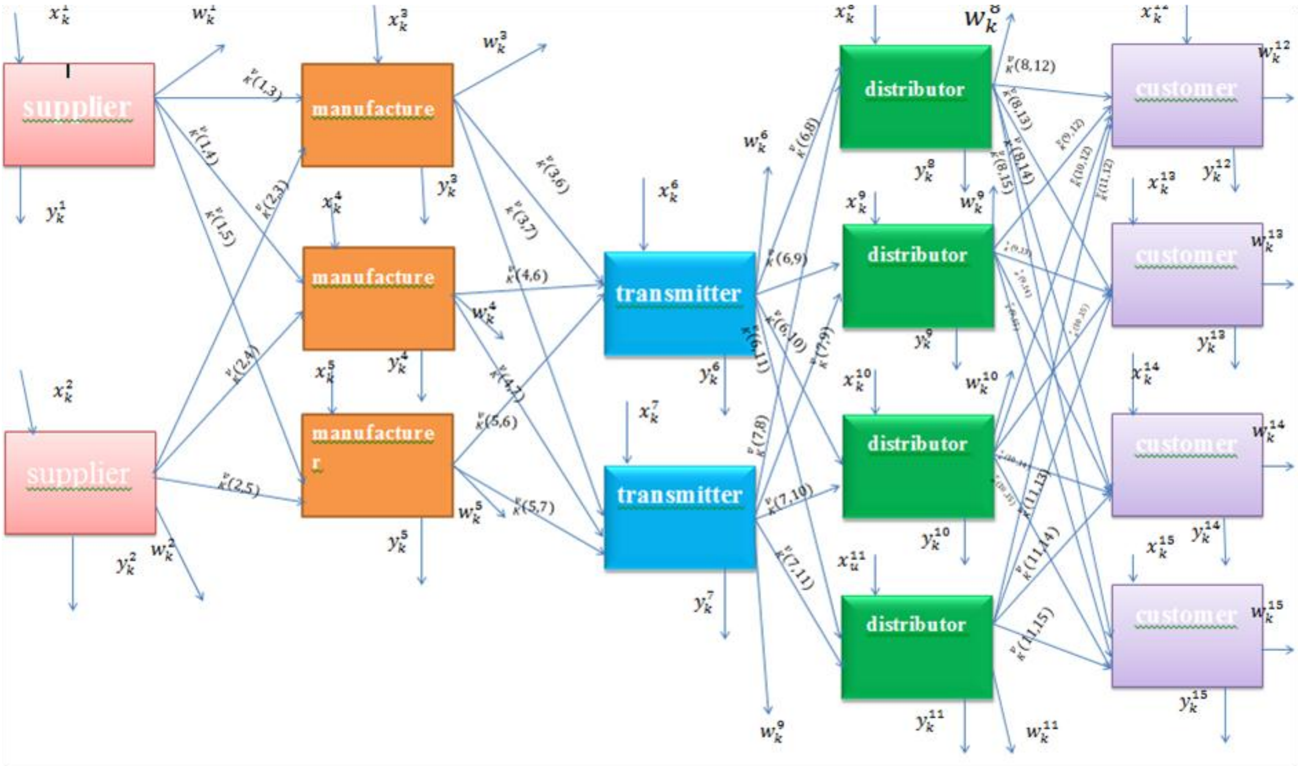


**Figure 2.** The supply chain structure.

Figure 2 shows an electricity supply chain structure in the power industry. The electricity supply chains are power suppliers in industry activity. 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. 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 transmissions companies to distributions companies and finally from them to customers. These measures indicate entities' relationship in the supply chain. However, each division of entities operates in depending on other divisions per stage of economic activities and supply chains compete to high efficiency earn in economic business. The whole goal examines the corporate sustainability of the Iranian power industry to environmental and operational efficiency increase to wasted energy reduction and environment protection of harmful gas emissions in production processes.

The outputs set can be separately defined for the partners of the supply chain as follows.

$$P_s\left(x\right)=\begin{cases} \left(v,w\right)\left|\sum_{k=1}^{k}\lambda_k^h\ v_{mk}^{\left(h,h'\right)}+s_{mk}^{\left(h,h'\right)}=\sum_{k=1}^{K}\lambda_k^{h'}\ v_{mk}^{\left(h,h'\right)}\right. & h=1,\ldots,h_s \\ & h'=1,\ldots,h_m \\ & m=1,\ldots,M_s \\ \sum_{k=1}^{K}\lambda_k^h\ y_{rk}^h\geq y_{ro} & h=1,\ldots,h_s \\ & r=1,\ldots,S_s \\ \sum_{k=1}^{K}\lambda_k^h\ w_{jk}^h=w_{jo} & j=1,\ldots,J_s \\ & h=1,\ldots.,h_s \\ \sum_{k=1}^{K}\left(\lambda_k^h+\mu_k^h\right)\ x_{nk}\leq x_{no} & n=1,\ldots,N_s \\ \sum_{k=1}^{K}\left(\lambda_k^h+\mu_k^h\right)=1 & h=1,\ldots,h_s \\ \lambda_k,\mu_k\geq 0 \qquad \mu\geq 0 & k=1,\ldots,K \\ s_{mk}^{\left(h,h'\right)}\ free & m=1,\ldots,M_s \end{cases} \tag{1}$$

$$P_m\left(x\right)=\begin{cases} \left(v,w\right)\left|\sum_{k=1}^{K}\lambda_k^h\ v_{mk}^{\left(h,h'\right)}+s_{mk}^{\left(h,h'\right)}=\sum_{k=1}^{K}\lambda_k^{h'}\ v_{mk}^{\left(h,h'\right)}\right. & h=1,\ldots,h_m \\ \sum_{k=1}^{K}\lambda_k^h\ y_{rk}^h\geq y_{ro}^h & h'=1,\ldots,h_d \\ & m=1,\ldots,M_m \\ \sum_{k=1}^{K}\lambda_k^h\ w_{jk}^h=w_{jo}^h & h=1,\ldots.,h_m \\ & r=1,\ldots.,S_m \\ \sum_{k=1}^{K}\left(\lambda_k^h+\mu_k^h\right)\ x_{nk}^h\leq x_{no}^h & j=1,\ldots.,J_m \\ & h=1,\ldots.,h_m \\ \sum_{k=1}^{K}\left(\lambda_k^h+\mu_k^h\right)=1 & n=1,\ldots.,N_m \\ \lambda_k,\mu_k\geq 0 & h=1,\ldots.,h_m \\ & k=1,\ldots.,K \\ s_{mk}^{\left(h,h'\right)}\ free & m=1,\ldots.,M_m \end{cases} \tag{2}$$

$$P_T(x) = \begin{cases} (v,w) \left| \sum_{k=1}^{K} \lambda_k^h \; v_{mk}^{(h,h')} + s_m^{(h,h')} = \sum_{k=1}^{K} \lambda_k^h \; v_{mk}^{(h,h')} \right. & \begin{matrix} h = 1,\dots,h_t \\ h' = 1,\dots h_d \\ m = 1,\dots M_t \end{matrix} \\ \sum_{k=1}^{K} \lambda_k^h w_{jk}^h = w_{jo} & \begin{matrix} h = 1,\dots,h_t \\ r = 1,\dots,s_t \end{matrix} \\ \sum_{k=1}^{K} \left(\lambda_k^h + \mu_k^h\right) x_{nk} \le x_{no} & \begin{matrix} j = 1,\dots j_t \\ h = 1,\dots,h_t \\ n = 1,\dots N_t \end{matrix} \\ \sum_{K=1}^{K} \left(\lambda_k^h + \mu_k^h\right) = 1 & h = 1,\dots,h_t \\ s_m^{(h,h')} \; free & h = 1,\dots,h_t \\ \lambda_k, \mu_k \ge \circ & \begin{matrix} k = 1,\dots K \\ m = 1,\dots M_t \end{matrix} \end{cases} \quad (3)$$

$$P_D(x) = \begin{cases} (v,w) \left| \sum_{k=1}^{K} \lambda_k^h \; v_{mk}^{(h,h')} + s_{mk}^{(h,h')} = \sum_{k=1}^{K} \lambda_k^{h'} \; v_{mk}^{(h,h')} \right. & \begin{matrix} h = 1,\dots,h_d \\ h' = 1,\dots h_c \\ m = 1,\dots M_d \end{matrix} \\ \sum_{k=1}^{K} \lambda_k^h w_{jk}^h = w_{jo} & \begin{matrix} h = 1,\dots,h_d \\ r = 1,\dots,s_d \end{matrix} \\ \sum_{k=1}^{K} \left(\lambda_k^h + \mu_k^h\right) x_{nk} \le x_{no} & \begin{matrix} j = 1,\dots, j_d \\ h = 1,\dots,h_d \\ n = 1,\dots N_d \end{matrix} \\ \sum_{K=1}^{K} \left(\lambda_k^h + \mu_k^h\right) = 1 & h = 1,\dots,h_d \\ s_{mk}^{(h,h')} \; free & h = 1,\dots,h_d \\ \lambda_k, \mu_k \ge \circ & \begin{matrix} k = 1,\dots,K \\ m = 1,\dots,M_d \end{matrix} \end{cases} \quad (4)$$

$$P_C(x) = \begin{cases} \sum_{k=1}^{K} \lambda_k^h y_{rk}^h \ge y_{ro}^h & \begin{matrix} h = 1,\dots,h_c \\ r = 1,\dots,s_c \end{matrix} \\ \sum_{k=1}^{K} \lambda_k^h w_{jk}^h = w_{jo} & \\ \sum_{k=1}^{K} \left(\lambda_k^h + \mu_k^h\right) x_{nk} \le x_{no}^h & \begin{matrix} h = 1,\dots,h_c \\ j = 1,\dots, j_d \end{matrix} \\ \sum_{k=1}^{K} (\lambda_k^h + \mu_k^h) = 1 & n = 1,\dots,N_c \\ \lambda_k, \mu_k \ge 0 & \begin{matrix} h = 1,\dots,h_c \\ k = 1,\dots,k \\ m = 1,\dots m_c \end{matrix} \end{cases} \quad (5)$$

Therefore, outputs set can be defined to a supply chain which comprises an arbitrary number of each division type and production indexes. In particular, we develop outputs set both non-cooperative and cooperative or centralize approaches to performance evaluation of a sustainable supply chain. In the result, outputs set of overall supply chain can be formed of all of its partners outputs set in production processes as follows.

$$\left\{\begin{array}{ll}
(v,w)\left|\sum_{k=1}^{K}\lambda_k^h v_{mk}^{(h,h')}+s_{mk}^{(h,h')}=\sum_{k=1}^{K}\lambda_k^h v_{mk}^{(h,h')}\right. & h=1,\dots h_s, m=1,\dots M_s, h'=1,\dots h_m \\
\sum_{k=1}^{K}\lambda_k^h v_{mk}^{(h,h')}+s_{mk}^{(h,h')}=\sum_{k=1}^{K}\lambda_k^h v_{mk}^{(h,h')} & h=1,\dots h_m, m=1,\dots M_m, h'=1,\dots h_t \\
\sum_{k=1}^{K}\lambda_k^h v_{mk}^{(h,h')}+s_{mk}^{(h,h')}=\sum_{k=1}^{K}\lambda_k^h v_{mk}^{(h,h')} & h=1,\dots h_t, m=1,\dots M_t, h'=1,\dots h_d \\
\sum_{k=1}^{K}\lambda_k^h v_{mk}^{(h,h')}+s_{mk}^{(h,h')}=\sum_{k=1}^{K}\lambda_k^h v_{mk}^{(h,h')} & h=1,\dots h_d, m=1,\dots M_d, h'=1,\dots h_c \\
\sum_{k=1}^{K}\lambda_k^h y_{rk}^h \ge y_{ro}^h & h=1,\dots h_s, r=1,\dots S_s \\
\sum_{k=1}^{K}\lambda_k^h y_{rk}^h \ge y_{ro}^h & h=1,\dots h_m, r=1,\dots S_m \\
\sum_{k=1}^{K}\lambda_k^h y_{rk}^h \ge y_{ro}^h & h=1,\dots h_t, r=1,\dots S_t \\
\sum_{k=1}^{K}\lambda_k^h y_{rk}^h \ge y_{ro}^h & h=1,\dots h_d, r=1,\dots S_d \\
\sum_{k=1}^{K}\lambda_k^h y_{rk}^h \ge y_{ro}^h & h=1,\dots h_c, r=1,\dots S_c \\
\sum_{k=1}^{K}\lambda_k^h w_{jk}^h = w_{jo}^h & j=1,\dots j_s\ ,\ h=1,\dots h_s \\
\sum_{k=1}^{K}\lambda_k^h w_{jk}^h = w_{jo}^h & j=1,\dots j_m\ ,\ h=1,\dots h_m \\
\sum_{k=1}^{K}\lambda_k^h w_{jk}^h = w_{jk}^h & j=1,\dots j_t\ ,\ h=1,\dots h_t \\
\sum_{k=1}^{K}\lambda_k^h w_{jk}^h = w_{jo}^h & j=1,\dots j_d, h=1,\dots h_d \\
\sum_{k=1}^{K}\lambda_k^h w_{jk}^h = w_{jo}^h & j=1,\dots j_c\ ,\ h=1,\dots h_c \\
\sum_{k=1}^{K}\left(\lambda_k^h+\mu_k^h\right)x_{nk} \le x_{no}^h & n=1,\dots N_s\ ,\ h=1,\dots h_s \\
\sum_{k=1}^{K}\left(\lambda_k^h+\mu_k^h\right)x_{nk} \le x_{no}^h & n=1,\dots N_m\ ,\ h=1,\dots h_m \\
\sum_{k=1}^{k}(\lambda_k^h+\mu_k^h)x_{nk} \le x_{no}^h & n=1,\dots N_t\ ,\ h=1,\dots h_t \\
\sum_{k=1}^{K}\left(\lambda_k^h+\mu_k^h\right)x_{nk} \le x_{no}^h & n=1,\dots N_d, h=1,\dots h_d \\
\sum_{k=1}^{K}\left(\lambda_k^h+\mu_k^h\right)x_{nk} \le x_{no}^h & n=1,\dots N_c\ ,\ h=1,\dots h_c \\
\sum_{k=1}^{K}\left(\lambda_k^h+\mu_k^h\right)=1 & \forall h, h=1,\dots.H \\
 & \forall k, k=1,\dots.k \\
\lambda_k, \mu_k \ge 0\ ,\quad s_{mk}^{(h,h')}\ \ free &
\end{array}\right. \tag{6}$$

## 4. Proposed model

Now, we present our cooperative approach to evaluate the sustainability of a supply chain as:

$$\theta = Min \sum_{h=1}^{H} W_h \varphi_o^h$$

$$s.t \quad \sum_{k=1}^{k} \lambda_k^h v_{m\,k}^{(h,h')} + s_{mk}^{(h,h')} = \sum \lambda_k^{h'} v_{mk}^{(h,h')} \qquad h=1,\dots h_s, m=1,\dots M_s, h'=1,\dots h_m$$

$$\sum_{k=1}^{K} \lambda_k^h v_{mk}^{(h,h')} + s_{mk}^{(h,h')} = \sum \lambda_k^{h'} v_{mk}^{(h,h')} \qquad h=1,\dots h_m, m=1,\dots M_m, h'=1,\dots h_t$$

$$\sum_{k=1}^{K} \lambda_k^h v_{mk}^{(h,h')} + s_{mk}^{(h,h')} = \sum_{k=1}^{K} \lambda_k^{h'} v_{mk}^{(h,h')} \qquad h=1,\dots h_t, m=1,\dots M_t, h'=1,\dots h_d$$

$$\sum_{k=1}^{k} \lambda_k^h v_{mk}^{(h,h')} + s_{mk}^{(h,h')} = \sum \lambda_k^{h1} v_{mk}^{(h,h')} \qquad h=1,\dots h_d, m=1,\dots M_d, h'=1,\dots h_c$$

$$\sum_{k=1}^{k} \lambda_k^h y_{rk}^h \geq y_{ro}^h \qquad h=1,\dots h_s, r=1,\dots S_s$$

$$\sum_{k=1}^{k} \lambda_k^h y_{rk}^h \geq y_{ro}^h \qquad h=1,\dots h_m, r=1,\dots S_m$$

$$\sum_{k=1}^{K} \lambda_k^h y_{rk}^h \geq y_{ro}^h \qquad h=1,\dots h_t, r=1,\dots S_t$$

$$\sum_{k=1}^{k} \lambda_k^h y_{rk}^h \geq y_{ro}^h \qquad h=1,\dots h_d, r=1,\dots S_d$$

$$\sum_{k=1}^{k} \lambda_k^h y_{rk}^h \geq y_{ro}^h \qquad h=1,\dots h_c, r=1,\dots S_c$$

$$\sum_{k=1}^{k} \lambda_k^h w_{jk}^h = \varphi_o^h w_{jo}^h \qquad j=1,\dots j_s, h=1,\dots h_s$$

$$\sum_{k=1}^{k} \lambda_k^h w_{jk}^h = \varphi_o^h w_{jo}^h \qquad j=1,\dots j_m, h=1,\dots h_m$$

$$\sum_{k=1}^{K} \lambda_k^h w_{jk}^h = \varphi_o^h w_{jo}^h \qquad j=1,\dots j_t, h=1,\dots h_t$$

$$\sum_{k=1}^{k} \lambda_k^h w_{jk}^h = \varphi_o^h w_{jo}^h \qquad j=1,\dots j_d, h=1,\dots h_d$$

$$\sum_{k=1}^{k} \lambda_k^h w_{jk}^h = \varphi_h w_{jo}^h \qquad j=1,\dots j_c, h=1,\dots h_c$$

$$\sum_{k=1}^{k} \left(\lambda_k^h + \mu_k^h\right) x_{nk}^h \leq x_{no}^h \qquad h=1,\dots,h_d \;, n=1,\dots,N_d$$

$$\sum_{k=1}^{k} \left(\lambda_k^h + \mu_k^h\right) x_{nk}^h \leq x_{no}^h \qquad h=1,\dots h_d \;, n=1,\dots N_m$$

$$\sum_{k=1}^{K}(\lambda_k^h + \mu_k^h)x_{nk}^h \le x_{no}^h \qquad h=1,\dots h_t,\quad n=1,\dots N_t$$
$$\sum_{k=1}^{k}\left(\lambda_k^h + \mu_k^h\right)x_{nk}^h \le x_{no}^h \qquad h=1,\dots,h_d\ ,n=1,\dots,N_d$$
$$\sum_{k=1}^{k}\left(\lambda_k^h + \mu_k^h\right)x_{nk}^h \le x_{no}^h \qquad h=1,\dots h_c, n=1,\dots N_c$$
$$\sum_{k=1}^{k}\left(\lambda_k^h + \mu_k^h\right)=1 \qquad \begin{array}{l}\forall h, h=1,\dots .H\\ \forall k, k=1,\dots .k\end{array}$$
$$\phi_o^h \ge 0,\quad s_{mk}^{(h,h')}\ free$$
$$\lambda_k,\mu_k \ge 0 \tag{7}$$

One straightforward approach to calculate the effect of production factors is non-cooperative network method in which each member of each stage is evaluated separately as follows.

$$Min\ \ \gamma = \phi_o^{h_s}$$
$$\sum_{k=1}^{k}\lambda_k^h v_{mk}^{(h,h')} + s_{mk}^{(h,h')} = \sum \lambda_k^{h1} v_{mk}^{(h,h')} \qquad h\in h_s, m=1,\dots M_s, h'\in h_m$$
$$\sum_{k=1}^{k}\lambda_k^h y_{rk}^h \ge y_{ro}^h \qquad h\in h_s, r=1,\dots S$$
$$\sum_{k=1}^{k}\lambda_k^h w_{jk}^h = \phi_o^{h_s} w_{jo}^h \qquad j=1,\dots j_s, h\in h_s$$
$$\sum_{k=1}^{k}\left(\lambda_k^h + \mu_k^h\right)x_{nk}^h \le x_{no}^h \qquad h\in h_s, n=1,\dots N_s$$
$$\sum_{k=1}^{K}\left(\lambda_k^h + \mu_k^h\right)=1 \qquad \forall h\in h_s$$
$$\phi_o^{h_s} \ge 0,\ \lambda_k,\mu_k \ge 0\ ,\quad s_{mk}^{(h_s,h_m)}\ \ free\ ,\ \ \forall k, k=1,\dots .K \tag{8}$$

The above model measures the efficiency of supplier divisions in a supply chain. The performance evaluating efficiency of supply chain partners can be calculated by a model similar to (8). After measuring the optimal efficiency of each member of supply chain network by a model such as model (8) the efficiency of under consideration DMU (supply chain) calculate by weighted average of optimal efficiency of each division of the supply chain as follows.

$$\gamma_o^* = \frac{\sum_{h_s} w_{h_s}\mu_o^{h_s} + \sum_{h_m} w_{h_m}\mu_o^{h_m} + \sum_{h_t} w_{h_t}\mu_o^{h_t} + \sum_{h_d} w_{h_d}\mu_o^{h_d} + \sum_{h_c} w_{h_c}\mu_o^{h_c}}{\sum_{h_s} w_h + \sum_{h_m} w_h + \sum_{h_t} w_h + \sum_{h_d} w_h + \sum_{h_c} w_{h_c}} \tag{9}$$

In the above model is supposed a supply chain contains an arbitrary number of suppliers, manufacturers, transmitters, distributers and customers. The objective function of Model (7) indicates the weighted average of the efficiency of partners as weights could be obtained through an expert opinion processes. In this study we considered the different weights for partners of a particular stage of the network supply chain. $W_h,(h=1,...,H)$ are weights for H divisions that are defined by decision makers. The right and left hand sight of the first constraints categories indicates the intermediate measures exit from th division and enter to division, respectively. The fifth until the fourteenth constraints are corresponded to desirable and undesirable outputs respectively. Moreover, the fifteenth constraint until nineteenth constraint related to inputs of every division. The last constrains categories indicate variable return to scale in production processes. In addition, five pair $(\phi_o^{h_s},\lambda_k^{h_s}),(\phi_o^{h_m},\lambda_k^{h_m}),(\phi_o^{h_d},\lambda_k^{h_d}),(\phi_o^{hc},\lambda_k^{h_c})$, indicates the main decision variable analogous to suppliers, manufactures, transmitters, distributers and customers, respectively. In this model is CCR-efficient if. Model (10) propose a supply chain multistage network based on cooperative or centralized approach following the method of [6]. This model measures the level of unified efficiency (operational and environmental) where all slack variables of intermediate measures are considered unrestricted; this allows higher flexibility in material flow of intermediate measures.

**Proposition1.** Suppose $\theta_o^*,\gamma_o^*$ are the optimal objective function cooperative and non-cooperative models, respectively then $\gamma_o^*\le\theta_o^*$ where $o\in\{k=1,...,K\}$, See proof [21].

## 5. A real case on power industry

In this section, we apply the proposed model to the analysis of the power industry in Iran. In Subsection 5.1 we will describe the dataset and we will specify the inputs and outputs we will consider in our analysis, in Subsection 5.2 we will present the main results.

### *5.1. 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 (NOx) 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. The supply chains have been built in northern, southern, eastern, western and central districts of Iran. In this study, energy sectors or oil and gas fields and fineries supplying demand fuels of area power plants so that, the energy sections are considered as suppliers and the power plants of the districts are selected as manufactures (power producers) in supply chain construction. Likewise, the region power companies transmit produced power of the area power plants to dispatching to distributions companies that are placed in the area. Finally, the distributions companies dispatch power to consumers or the area residences. 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 two inputs (capital and labor) and produce one desirable (oil or gas) and one undesirable output (flaring gas). 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 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.

Transmitters transfer electricity from manufacturers to distributing companies and the capacity and length of the lines are considered as inputs in lines. 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 it to the final consumers. They use two inputs as capacity of the distribution lines and length of the distribution lines, 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, public, agriculture and industrial. Table 1 indicates the production factors used for supply chain evaluation.

More in detail, the parameters used to characterize this supply chain are defined as follows:

$h_s$: Numerator of division in the supplier level ($h_s$ = 1, 2)

$x_{1k}^{h_s}$: Capacity of oil ($10^3$ Barrels) and gas ($10^6$ $m^3$) fields of $h_s$ the supplier in kth supply chain.

$x_{2k}^{h_s}$: Number of employees from $h_s$th supplier in kth supply chain.

$y_{1k}^{h_s}$: Oil ($10^3$ Barrels) and gas ($10^6$ $m^3$) sold to other companies from the $h_s$th supplier in kth supply chain.

$w_{1k}^{h_s}$: Flaring gas of oil field ($10^3$ barrels) and gas field ($10^6$ $m^3$) of the $h_s$th supplier in the kth supply chain.

$h_m$: Numerator of division in the manufacturer level ($h_m$ = 3, 4, 5)

$x_{1k}^{h_m}$: Power nominal of $h_m$ th manufacturer in the kth supply chain ($10^6$ Kwh).

$x_{2k}^{h_m}$: Number of employees of $h_m$th manufacturer in the kth supply chain.

**Table 1.** Production factors in performance evaluation.

| Division | Numerator | Factors | Definition |
|---|---|---|---|
| Supplier | $h_s$ | $x_{1k}^{h_s}$ | Capacity of oil ($10^3$ Barrels) and gas($10^6$ $m^3$) |
| | | $x_{2k}^{h_s}$ | Number of employees |
| | | $y_{1k}^{h_s}$ | Oil ($10^3$ Barrels) and gas ($10^6$ $m^3$) sold |
| | | $w_{1k}^{h_s}$ | Flaring gas of oil field ($10^3$ barrels)and gas field($10^6$ $m^3$) |

*Continued on next page*

| Division | Numerator | Factors | Definition |
|---|---|---|---|
| Manufacturer | $h_m$ | $x_{1k}^{h_m}$ | Power nominal of power plants |
| | | $x_{2k}^{h_m}$ | Labor |
| | | $y_{1k}^{h_m}$ | Percentage of new construction of power plant |
| | | $w_{1k}^{h_m}$ | Emissions of $No_x$ harmful Substances($10^3$ Kg/$10^6$ K wh) |
| | | $w_{2k}^{h_m}$ | Emissions of $SO_x$ harmful Substances($10^3$ Kg/$10^6$ K wh) |
| | | $w_{3k}^{h_m}$ | Emission of $CO_2$ harmful Substances($10^3$ Kg/$10^6$ K wh) |
| Transmitter | $h_t$ | $x_{1k}^{h_t}$ | Capacity of regional company (M wa) |
| | | $x_{2k}^{h_t}$ | Length transmission line (Km circuit) |
| | | $y_{1k}^{h_t}$ | New construction of transmission lines (Km circuit) |
| | | $w_{1k}^{h_t}$ | Loose of transmission line (%) |
| Distribution | $h_d$ | $x_{1k}^{h_d}$ | Capacity of distribution lines (M wa) |
| | | $x_{2k}^{h_d}$ | Length transmission line (Km) |
| | | $y_{1k}^{h_d}$ | New construction of distribution lines (Km) |
| | | $w_{1k}^{h_d}$ | Percentage of losses of distribution line (%) |
| Customer | | $x_{1k}^{h_c}$ | Average cost with fuel subsidy (Rial) |
| | | $y_{1k}^{h_c}$ | Number of customers |
| | | $y_{2k}^{h_c}$ | Sales of electricit($10^6$ K wh) |
| | | $w_{1k}^{h_c}$ | Cut of power |
| | | $v_{mk}^{h,h'}$ | Material flow from division $h$ to division $h'$ ($10^6$ K wa) |

$w_{1k}^{h_s}$: Flaring gas of oil field ($10^3$ barrels) and gas field ($10^6$ $m^3$) of the $h_s$th supplier in the kth supply chain.

$h_m$ : Numerator of division in the manufacturer level ($h_m$ = 3, 4, 5)

$x_{1k}^{h_m}$ : Power nominal of $h_m$ th manufacturer in the kth supply chain ($10^6$ K wh).

$x_{2k}^{h_m}$ : Number of employees of $h_m$th manufacturer in the kth supply chain.

$y_{1k}^{h_m}$ : Percentage of new construction of power plant of the $h_m$th manufacturer in the kth supply chain

$w_{1k}^{h_m}$ : Emissions of $NO_x$ harmful substances of the $h_m$th manufacturer in the kth supply chain ($10^3$ Kg/$10^6$ K wh).

$w_{2k}^{h_m}$ : Emissions of $SO_x$ harmful substance of the $h_m$th manufacturer in the kth supply chain ($10^3$ Kg/$10^6$ Kwh).

$w_{3k}^{h_m}$ : Emission of $CO_2$ harmful substance of the $h_m$th manufacturer in the kth supply chain ($10^3$ Kg/$10^6$ K wh).

$h_t$ : Numerator of the divisions in the transmitters level ($h_t$ = 6, 7)

$x_{1k}^{h_t}$ : Capacity of regional company of the $h_t$th transmitter in the kth supply chain (M wa).

$x_{2k}^{h_t}$ : Length transmission line of the $h_t$ th transmitter in the kth supply chain (Km circuit).

$y_{1k}^{h_t}$ : New construction of transmission lines of the $h_t$th transmitter in the kth supply chain (Km circuit).

$w_{1k}^{h_d}$ : Loose of transmission line of $h_t$ th transmitter in the kth supply chain (%).

$h_d$ : Numerator of division in the distributer level ($h_d$: 8, 9, 10, 11)

$x_{1k}^{h_d}$ : Capacity of distribution lines of $h_d$th distributer company in the kth supply chain (M wa).

$x_{2k}^{h_d}$ : Length distribution line of the $h_d$th distributer in the kth supply chain (Km).

$y_{1k}^{h_d}$ : Meter of electricity of $h_d$th distributer in kth supply chain

$w_{1k}^{h_d}$ : Percentage of losses of distribution line of $h_d$th distributer in the kth supply chain

$h_c$ : Numerator of division in the customer level ($h_c$: 12, 13, 14, 15)

$x_{1k}^{h_c}$ : Average cost with fuel subsidy of the $h_c$th customer in the kth supply chain (Rial).

$y_{1k}^{h_c}$ : Number of customers of $h_c$th customer in the kth supply chain.

$y_{2k}^{h_c}$ : Sales of electricity of the $h_c$th customer in the kth supply chain ($10^6$ K wh).

$w_{1k}^{h_c}$ : Cut of power of the $h_c$th customer in the kth supply chain (minute/year).

$V_{mk}^{h,h'}$ : Material flow from division $h$ to division $h'$ ($10^6$ K wa).

The dataset has been collected from 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 output. 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 [22]. Supplier inputs are obtained from oil and gas fields statistics of energy industry in Iran. 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 0.03% rate of the annual production of oil and gas. Information related to the demand fuel of power plants is collected from TAVANIR Company [22] in power industry and they are considered as intermediate measure from oil and gas fields to power plants. The capacity of power plants is a proxy of the input capital (for a similar approach see [23]). 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 transmission division of TAVANIR company in power industry and losses of transmission line (undesirable output) is estimated with a 3.02% factor based on amount of loose of transmission in Iran. All of 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.

The data sets corresponding to the 10 supply chains (DMUs) under analysis are presented in Tables 2–16. Tables 2 and 3 show inputs and desirable and undesirable outputs for suppliers 1 and 2, respectively. In Tables 4–7, we present the data of manufacturer (level 2, 3, 4).Tables 8 and 9 show the data of transmitters with two inputs, one good output and one undesirable output, respectively. Tables 10–13 collect the data on distributors where two inputs, one desirable and one undesirable output are considered. Finally, in Tables 14–16 the data of customers are reported with one input, two desirable outputs and one undesirable output. The material flow or intermediate measure from suppliers to manufacturers, from manufacture's division to the transmitters from transmitters to distributors and from distributors to the customers are presented in Tables 17–22.

**Table 2.** The supplier level-inputs.

| DMU | supplier 1 (division 1) | | supplier 2 (division 2) | |
|---|---|---|---|---|
| | Capacity($10^3$ barrels) | labor | Capacity($10^3$ barrels) | labor |
| | $x_{1k}^1$ | $x_{2k}^1$ | $x_{1k}^2$ | $x_{2k}^2$ |
| 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.

| DMU | Supplier 1 (Division 1) | | Supplier 2 (Division 2) | |
|---|---|---|---|---|
| | Oil sold ($10^3$ barrels) | Gas flare($10^3$ barrels) | gas sold ($10^3$ barrels) | Gas flare($10^3$ barrels) |
| | $y_{1k}^1$ | $w_{1k}^1$ | $y_{1k}^2$ | $w_{1k}^2$ |
| 1 | 1739.693 | 54 | 1186.216 | 151.2 |
| 2 | 40572.996 | 1296 | 7203.230 | 345.6 |
| 3 | 8995.883 | 432 | 3726.203 | 183.6 |
| 4 | 26527.191 | 972 | 1930.025 | 140.4 |
| 5 | 4552.857 | 216 | 10438.190 | 367.2 |
| 6 | 23324.391 | 756 | 3350.675 | 183.6 |
| 7 | 17080.471 | 756 | 2353.130 | 172.8 |
| 8 | 15872.914 | 648 | 9455.104 | 345.6 |
| 9 | 6062.772 | 194.4 | 9849.593 | 367.2 |
| 10 | 25603.400 | 1296 | 2208.415 | 140.4 |

Calculations flaring gas and sold oil and gas.

**Table 4.** Manufacturers level inputs.

| DMU | Manufacturer 1 (Division 3) | | Manufacturer 2 (Divition 4) | | Manufacturer 3 (Division 5) | |
|---|---|---|---|---|---|---|
| | Power nominal ($10^6$ kwh) | labor | Power nominal ($10^6$ kwh) | labor | Power nominal ($10^6$ kwh) | labor |
| | $x_{1k}^3$ | $x_{2k}^3$ | $x_{1k}^4$ | $x_{2k}^4$ | $x_{1k}^5$ | $x_{2k}^5$ |
| 1 | 63224 | 4070 | 15408 | 1600 | 11903 | 1200 |
| 2 | 16200 | 2263 | 10400 | 700 | 2626.952 | 2600 |
| 3 | 10448 | 1000 | 5701.12 | 3300 | 16760 | 2005 |
| 4 | 8022.4 | 1000 | 8622.4 | 3300 | 8344 | 2005 |
| 5 | 5184 | 890 | 1920.48 | 900 | 16417.760 | 2823 |
| 6 | 13672.88 | 2300 | 3312 | 2500 | 3936 | 800 |
| 7 | 966.32 | 1450 | 8352 | 2700 | 17844.8 | 890 |
| 8 | 1491.2 | 1520 | 10320 | 2260 | 16800 | 1300 |
| 9 | 3872 | 1500 | 10590 | 3600 | 7072 | 4100 |
| 10 | 11453.6 | 3180 | 6787.200 | 760 | 2053.28 | 1590 |

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

**Table 5.** Manufacturers level desirable and undesirable outputs.

| DMU | Manufacturer 1 (Division 3) | | | |
|---|---|---|---|---|
| | Percentage of new power plant | Emissions of $NO_x$ ($10^3$ Kg/$10^6$ Kwh) | Emissions of $SO_x$ ($10^3$ Kg/$10^6$ Kwh) | Emissions of $SO_x$ ($10^3$ Kg/$10^6$ Kwh) |
| | $y_{1k}^3$ | $w_{1k}^3$ | $w_{2k}^3$ | $w_{3k}^3$ |
| 1 | 12.2 | 454610.278 | 23891876.280 | 288025420.100 |
| 2 | 12.2 | 302399.805 | 4207069.806 | 191952930.500 |
| 3 | 13 | 235104.740 | 195553.061 | 149621794 |
| 4 | 12.2 | 229464.218 | 12059407.75 | 145380628.200 |
| 5 | 73.6 | 43498.708 | 38755.471 | 27536231.770 |
| 6 | 100 | 256638.343 | 217529.667 | 163094448.800 |
| 7 | 85.5 | 6683.633 | 5954.829 | 4230977.926 |
| 8 | 85.5 | 15138.687 | 184259.151 | 9585079.623 |
| 9 | 13 | 92035.892 | 76552.691 | 58572086.910 |
| 10 | 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.

| DMU | | Manufacturer 2 (Division 4) | | |
|---|---|---|---|---|
| | Percentage of new power plant | Emissions of $NO_x$ ($10^3$ Kg/$10^6$ Kwh) | Emissions of $SO_x$ ($10^3$ Kg/$10^6$ Kwh) | Emissions of $SO_x$ ($10^3$ Kg/$10^6$ Kwh) |
| | $y_{1k}^4$ | $w_{1k}^4$ | $w_{2k}^4$ | $w_{3k}^4$ |
| 1 | 85.5 | 5715.366 | 5092.145 | 3618030.390 |
| 2 | 0 | 283431.105 | 14895617.700 | 179572190 |
| 3 | 12.2 | 174773.192 | 9070013.802 | 110729096.200 |
| 4 | 25.2 | 182851.984 | 152090.788 | 116367887.400 |
| 5 | 12.2 | 49845.037 | 2619587.603 | 3158009.070 |
| 6 | 85.5 | 27420.014 | 24430.049 | 17357845.530 |
| 7 | 12.2 | 273496.466 | 14373506.370 | 173277944.500 |
| 8 | 12.2 | 311634.456 | 21776302.480 | 197440862.200 |
| 9 | 98.8 | 176752.534 | 147351.908 | 112467128.500 |
| 10 | 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.

| DMU | Manufacturer 3 (Division 5) | | | |
|---|---|---|---|---|
| | Percentage of new power plant | Emissions of NOx ($10^3$ Kg/$10^6$ Kwh) | Emissions of SOx ($10^3$ Kg/$10^6$ Kwh) | Emissions of SOx ($10^3$ Kg/$10^6$ Kwh) |
| | $y_{1k}^5$ | $w_{1k}^5$ | $w_{2k}^5$ | $w_{3k}^5$ |
| 1 | 73.600 | 19603.894 | 17519.680 | 12447945.190 |
| 2 | 73.600 | 27423877.76 | 24433491.25 | 17360291475 |
| 3 | 98.800 | 212448.268 | 690393.877 | 135090771.800 |
| 4 | 13 | 140748.540 | 117070.408 | 89573051.780 |
| 5 | 87 | 300157.654 | 9178172.226 | 190308335.200 |
| 6 | 13 | 77463.980 | 64432.212 | 49298451.340 |
| 7 | 13 | 471751.939 | 21768344.370 | 299051808 |
| 8 | 13 | 510495.755 | 21776302.480 | 323709891.900 |
| 9 | 13 | 94829.614 | 78876.425 | 60350025.180 |
| 10 | 1.200 | 59895.401 | 3147780.793 | 37947663.670 |

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

**Table 8.** The transmitter level inputs.

| DMU | Transmitter 1 (division 6) | | Transmitter 2 (division 7) | |
|---|---|---|---|---|
| | Capacity of regional company (Mwa) | Length line (Km circuit) | Capacity of regional company (Mwa) | Length line (Km circuit) |
| | $x_{1k}^6$ | $x_{2k}^6$ | $x_{1k}^7$ | $x_{2k}^7$ |
| 1 | 27542 | 8704 | 25086 | 14697.700 |
| 2 | 41011 | 9127.800 | 4938 | 2244.500 |
| 3 | 13659 | 8643.400 | 41011 | 9127.800 |
| 4 | 16545 | 10367.900 | 41011 | 9127.800 |
| 5 | 6871 | 2850.700 | 13659 | 8643.400 |
| 6 | 14068 | 11166.400 | 4938 | 2244.500 |
| 7 | 14171 | 5780.500 | 8762 | 4480.400 |
| 8 | 10812 | 8273.300 | 15407 | 6095.800 |
| 9 | 25086 | 14697.700 | 7367 | 3776.100 |
| 10 | 10812 | 8273.300 | 7716.400 | 1453.800 |

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

**Table 9.** Transmitter level desirable and undesirable outputs.

| DMU | Transmitter 1 (division 6) | | Transmitter 2 (division 7) | |
|---|---|---|---|---|
| | New construction (Km circuit). | Loose of power (%) | New construction (Km circuit). | Loose of power (%) |
| | $y_{1k}^{6}$ | $w_{1k}^{6}$ | $y_{1k}^{7}$ | $w_{1k}^{7}$ |
| 1 | 990 | 508.845 | 1541.400 | 51.880 |
| 2 | 1302.300 | 200.566 | 110 | 301.829 |
| 3 | 1961.500 | 175.381 | 1302.300 | 357.789 |
| 4 | 1596 | 328.197 | 1302.300 | 117.468 |
| 5 | 324 | 67.759 | 1961.500 | 263.987 |
| 6 | 431.300 | 254.862 | 110 | 107.780 |
| 7 | 1576.200 | 447.605 | 747 | 61.919 |
| 8 | 601.200 | 373.774 | 386 | 202.020 |
| 9 | 1541.400 | 273.358 | 110 | 84.462 |
| 10 | 601.200 | 294.146 | 1453.800 | 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) | |
|---|---|---|---|---|
| | Capacity of distribution line (Mva) | length distribution line (Km) | Capacity of distribution line (Mva) | length distribution line(Km) |
| | $x_{1k}^{8}$ | $x_{2k}^{8}$ | $x_{1k}^{9}$ | $x_{2k}^{9}$ |
| 1 | 7792 | 40437 | 4067 | 60332 |
| 2 | 11349 | 64702 | 2330 | 19739 |
| 3 | 11349 | 64702 | 3068 | 28043 |
| 4 | 8612 | 12406 | 1787 | 8942 |
| 5 | 900 | 13383 | 2480 | 26770 |
| 6 | 11349 | 64702 | 3175 | 15731 |
| 7 | 3639 | 37153 | 1444 | 13785 |
| 8 | 2084 | 51688 | 4221 | 24689 |
| 9 | 7792 | 40437 | 1894 | 18162 |
| 10 | 2690 | 35606 | 2084 | 51688 |

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

**Table 11.** The distributor level inputs.

| DMU | Distributor 3 (division 10) | | Distributor 4 (division 11) | |
|---|---|---|---|---|
| | Capacity of distribution line (Mva) $x_{1k}^{10}$ | length distribution line (Km) $x_{2k}^{10}$ | Capacity of distribution line (Mva) $x_{1k}^{11}$ | length distribution line (Km) $x_{2k}^{11}$ |
| 1 | 3325 | 13761 | 4492 | 10052 |
| 2 | 1787 | 18122 | 1324 | 11101 |
| 3 | 3651 | 32533 | 900 | 13383 |
| 4 | 1874 | 12075 | 3175 | 56184 |
| 5 | 3965 | 32533 | 3068 | 28043 |
| 6 | 1324 | 11101 | 1894 | 18162 |
| 7 | 900 | 13383 | 11349 | 64702 |
| 8 | 4067 | 60332 | 5395 | 52340 |
| 9 | 3325 | 13761 | 4067 | 60332 |
| 10 | 4067 | 60332 | 5395 | 52340 |

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

**Table 12.** Distributor level desirable and undesirable outputs.

| DMU | Distributor 1 (Division 8) | | Distributor 2 (Divitson 9) | |
|---|---|---|---|---|
| | Meter of electricity $y_{1k}^{8}$ | Power losses (%) $w_{1k}^{8}$ | Meter of electricity $y_{1k}^{9}$ | Power losses (%) $w_{1k}^{9}$ |
| 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 (Divition 11) | |
|---|---|---|---|---|
| | Meter of electricity $y_{1k}^{10}$ | Power losses (%) $w_{1k}^{10}$ | Meter of electricity $y_{1k}^{11}$ | Power losses (%) $w_{1k}^{11}$ |
| 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) |
|---|---|---|---|---|
| | Average cost (Rial) $x_{1k}^{12}$ | Average cost (Rial) $x_{1k}^{13}$ | Average cost (Rial) $x_{1k}^{14}$ | Average cost (Rial) $x_{1k}^{15}$ |
| 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 |
| 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 desirable and undesirable outputs.

| DMU | Customer 1 (division 12) | | | Customer 2 (division 13) | | |
|---|---|---|---|---|---|---|
| | Number of customers $y_{1k}^{12}$ | Sales of electricity $y_{2k}^{12}$ | Cut of power $w_{1k}^{12}$ | Number of customers $y_{1k}^{13}$ | Sales of electricity $y_{2k}^{13}$ | Cut of power $w_{2k}^{13}$ |
| 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 16.** The Customer level desirable and undesirable outputs.

| DMU | Customer 3 (division 14) | | | Customer 4 (division 15) | | |
|---|---|---|---|---|---|---|
| | Number of customers $y_{1k}^{14}$ | Sales Of Electricity $y_{2k}^{14}$ | Cut of power $w_{1k}^{14}$ | Number Of customers $y_{1k}^{15}$ | Sales Of electricity $y_{2k}^{15}$ | Cut of power $w_{1k}^{15}$ |
| 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.

**Table 17.** The material flow (intermediate products desirable outputs) (106 Kwa).

| DMU | $v_{1_{(1,3)}j}^{(1,3)}$ | $v_{1_{(1,4)}}^{(1,4)}$ | $v_{1_{(1,5)}}^{(1,5)}$ | $v_{1_{(2,3)}}^{(2,3)}$ | $v_{1_{(2,4)}}^{(2,4)}$ | $v_{1_{(2,5)}}^{(2,5)}$ |
|---|---|---|---|---|---|---|
| 1 | 60.307 | 0 | 0 | 2875.091 | 220.4 | 758.293 |
| 2 | 2064.952 | 203.532 | 358.519 | 2336.167 | 1695.484 | 258.119 |
| 3 | 2548.744 | 1724.993 | 1130.38 | 129.687 | 801.96 | 1462.15 |
| 4 | 2860.549 | 1507.982 | 1504.277 | 932.017 | 1093.177 | 724.781 |
| 5 | 503.449 | 378.483 | 1765.210 | 467.063 | 286.531 | 1048.213 |
| 6 | 1839.757 | 35.852 | 0 | 1886.773 | 285.119 | 597.451 |
| 7 | 16.681 | 2028.841 | 6074.007 | 93.521 | 1421.775 | 1891.574 |
| 8 | 0 | 5307.55 | 419.537 | 206.169 | 1116.091 | 742.636 |
| 9 | 203.507 | 102.486 | 111.235 | 570.477 | 1230.004 | 589.926 |
| 10 | 142.515 | 15401.05 | 2053.038 | 1645.455 | 705.324 | 120.806 |

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

**Table 18.** The material flow (intermediate products desirable outputs) (106 Kwa).

| DMU | $v_{1_{(2,7)}j}^{(3,6)}$ | $v_{1_{(3,7)}}^{(3,7)}$ | $v_{1_{(4,6)}}^{(4,6)}$ | $v_{1_{(4,7)}}^{(4,7)}$ | $v_{1_{(5,6)}}^{(5,6)}$ | $v_{1_{(5,7)}}^{(5,7)}$ |
|---|---|---|---|---|---|---|
| 1 | 16849.166 | 0 | 0 | 954.941 | 0 | 762.931 |
| 2 | 6641.271 | 2846.259 | 0 | 6081.337 | 0 | 1066.752 |
| 3 | 0 | 7144.31 | 3791.372 | 0 | 2015.572 | 4703.002 |
| 4 | 4923.416 | 0 | 1666.995 | 3889.655 | 4277.035 | 0 |
| 5 | 1174.200 | 503.228 | 1069.482 | 0 | 0 | 8238.071 |
| 6 | 8439.133 | 0 | 0 | 1214.901 | 0 | 2353.958 |
| 7 | 0 | 259.243 | 4179.104 | 1791.044 | 10644.237 | 0 |
| 8 | 550.870 | 0 | 0 | 6689.385 | 11825.766 | 0 |
| 9 | 0 | 2796.766 | 5426.567 | 0 | 3625.006 | 0 |
| 10 | 7291.361 | 0 | 2448.571 | 0 | 0 | 1285.702 |

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

**Table 19.** The material flow (intermediate products desirable outputs) (106 Kwa).

| DMU | $v_{1_{(6,8)}}^{(6,8)}$ | $v_{1_{(6,9)}}^{(6,9)}$ | $v_{1_{(6,10)}}^{(6,10)}$ | $v_{1_{(6,11)}}^{(6,11)}$ | $v_{1_{(7,8)}}^{(7,8)}$ | $v_{1_{(7,9)}}^{(7,9)}$ |
|---|---|---|---|---|---|---|
| 1 | 11438.225 | 0 | 0 | 4902.096 | 0 | 499.798 |
| 2 | 4508.493 | 1932.211 | 0 | 0 | 0 | 0 |
| 3 | 0 | 0 | 3942.347 | 1689.577 | 8042.661 | 3446.851 |
| 4 | 0 | 7377.474 | 3161.775 | 0 | 2640.531 | 0 |
| 5 | 652.777 | 0 | 0 | 1523.146 | 0 | 2543.194 |
| 6 | 0 | 8184.271 | 0 | 0 | 356.886 | 0 |
| 7 | 10062.973 | 0 | 0 | 4312.703 | 0 | 1391.858 |
| 8 | 8402.003 | 0 | 0 | 3600.858 | 0 | 4399.742 |
| 9 | 0 | 0 | 2633.465 | 6144.751 | 813.691 | 1898.613 |
| 10 | 0 | 6612.050 | 2833.736 | 0 | 827.812 | 0 |

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

**Table 20.** The material flow (intermediate products desirable outputs) (106 Kwa).

| DMU | $v_{1_{(7,10)}\,j}^{(7,10)}$ | $v_{1_{(7,11)}}^{(7,11)}$ | $v_{1_{(8,12)}}^{(8,12)}$ | $v_{1_{(8,13)}}^{(8,13)}$ | $v_{1_{(8,14)}}^{(8,14)}$ | $v_{1_{(8,15)}}^{(8,15)}$ |
|---|---|---|---|---|---|---|
| 1 | 1166.195 | 0 | 3888.996 | 2058.880 | 1715.834 | 3774.614 |
| 2 | 2907.756 | 6784.863 | 1532.888 | 811.529 | 676.274 | 1487.803 |
| 3 | 0 | 0 | 2734.506 | 1447.680 | 1206.400 | 2654.080 |
| 4 | 574.437 | 377.219 | 897.781 | 475.297 | 396.080 | 871.375 |
| 5 | 5934.119 | 0 | 221.944 | 117.500 | 97.917 | 215.416 |
| 6 | 2498.201 | 713.772 | 121.341 | 64.239 | 53.533 | 117.772 |
| 7 | 596.511 | 0 | 3421.411 | 1811.335 | 1509.446 | 3320.781 |
| 8 | 1885.604 | 0 | 2856.681 | 1512.361 | 1260.300 | 2772.661 |
| 9 | 0 | 0 | 276.655 | 146.464 | 122.054 | 268.518 |
| 10 | 0 | 374.062 | 296.755 | 157.106 | 130.922 | 288.028 |

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

**Table 21.** The material flow (intermediate products desirable outputs) (106 Kwa).

| DMU | $v_{1_{(9,12)}j}^{(9,12)}$ | $v_{1_{(9,13)}}^{(9,13)}$ | $v_{1_{(9,14)}}^{(9,14)}$ | $v_{1_{(9,15)}}^{(9,15)}$ | $v_{1_{(10,12)}}^{(10,12)}$ | $v_{1_{(10,13)}}^{(10,13)}$ |
|---|---|---|---|---|---|---|
| 1 | 169.931 | 89.964 | 74.970 | 164.933 | 396.506 | 209.915 |
| 2 | 656.952 | 347.798 | 289.832 | 637.630 | 988.637 | 523.396 |
| 3 | 1171.931 | 620.434 | 517.029 | 1137.463 | 1340.398 | 709.622 |
| 4 | 2508.341 | 1327.945 | 1106.621 | 2434.567 | 1331.512 | 704.918 |
| 5 | 864.686 | 457.775 | 381.490 | 839.254 | 2017.600 | 1068.141 |
| 6 | 2782.652 | 1473.169 | 1227.641 | 2700.809 | 849.388 | 449.376 |
| 7 | 473.232 | 250.534 | 208.779 | 459.311 | 202.814 | 107.372 |
| 8 | 1495.912 | 791.954 | 659.961 | 1451.915 | 641.105 | 339.409 |
| 9 | 645.528 | 341.750 | 284.792 | 626.542 | 895.378 | 474.024 |
| 10 | 2248.097 | 1190.169 | 991.808 | 2181.977 | 963.470 | 510.072 |

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

**Table 22.** The material flow (intermediate products desirable outputs) (106 Kwa).

| DMU | $v_{1_{(10,14)}j}^{(10,14)}$ | $v_{1_{(10,15)}}^{(10,15)}$ | $v_{1_{(11,12)}}^{(11,12)}$ | $v_{1_{(11,13)}}^{(11,13)}$ | $v_{1_{(11,14)}}^{(11,14)}$ | $v_{1_{(11,15)}}^{(11,15)}$ |
|---|---|---|---|---|---|---|
| 1 | 174.922 | 384.844 | 1666.713 | 882.377 | 735.314 | 1617.692 |
| 2 | 436.163 | 959.559 | 2306.820 | 1221.257 | 1017.714 | 2238.972 |
| 3 | 591.352 | 1300.974 | 574.456 | 304.124 | 253.437 | 557.560 |
| 4 | 587.432 | 1292.350 | 128.254 | 67.899 | 56.583 | 124.482 |
| 5 | 890.118 | 1958.259 | 517.870 | 274.166 | 228.472 | 502.638 |
| 6 | 374.830 | 824.406 | 242.682 | 128.479 | 107.066 | 235.545 |
| 7 | 89.477 | 196.849 | 1466.319 | 776.276 | 646.905 | 1423.192 |
| 8 | 282.841 | 622.250 | 1224.292 | 648.155 | 540.129 | 1188.283 |
| 9 | 395.020 | 869.043 | 2089.215 | 1106.055 | 921.713 | 2027.768 |
| 10 | 425.060 | 935.133 | 127.181 | 67.331 | 56.109 | 123.441 |

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

According to fuzzy–weighted average definition, the fuzzy index has been calculated and the entity weights, division weights and the overall weights of the 15 divisions are presented in Table 23.

**Table 23.** The weights of the divisions.

| Supply chains Entity | Importance Weights | Division | Division Weight | Overall Weight |
|---|---|---|---|---|
| Suppliers | 0.15 | $S_1$ | 0.45 | 0.0675 |
| | | $S_2$ | 0.55 | 0.0825 |
| Manufacturers | 0.20 | $M_1$ | 0.35 | 0.07 |
| | | $M_2$ | 0.30 | 0.06 |
| | | $M_3$ | 0.35 | 0.07 |
| Transmitters | 0.20 | T1 | 0.65 | 0.13 |
| | | T2 | 0.35 | 0.07 |
| Distributers | 0.15 | D1 | 0.25 | 0.0375 |
| | | D2 | 0.30 | 0.045 |
| | | D3 | 0.20 | 0.03 |
| | | D4 | 0.25 | 0.0375 |
| Customers | 0.30 | C1 | 0.27 | 0.081 |
| | | C2 | 0.24 | 0.072 |
| | | C3 | 0.20 | 0.06 |
| | | C4 | 0.29 | 0.087 |

### *5.2. Results*

We now describe the results obtained in the new proposed approach. First the model is applied to estimate the efficiency score of supply chain 10 (DMUS). All models are solved by a linear programming solver using the GAMS software on a 8 GB RAM, 2.0 GHz desktop computer, the runtime of the computation in this study is negligible in model. The results are listed in Table 24.

The first column of Table 24 represents the global efficiency score of the supply chain. It can be easily seen that no DMU can reach efficiency equal to 1. This implies that all the 10 supply chains can improve their performance in some of the divisions. Supply chain number 7 is the one that reaches the highest score (0.90) while supply chain number 9 is the worst performing one. Columns from 2 to 15 report the efficiency scores of all the 15 divisions. In this way, we can exploit which divisions are more efficient in the various supply chains (looking at the data in columns) and, in parallel, per each DMU which are the divisions that are more efficient and which are the ones to be improved.

Looking vertically in the tables, the more efficient divisions are divisions 3, 10 and 4, with efficient values (80% and 90% of the total), respectively. This implies that Manufacturers 2 and 3 and Distributer 3 are the more efficient ones concerning to the other divisions. Just three efficient units (30%) are obtained in the case of divisions 6, 8 and 12 (Transmitter 1, Distributer 1 and

Customer 1, respectively).

**Table 24.** The cooperative efficiency scores of supply chains (DMUs).

| DMU | $\theta_o$ | $\varphi_o^{Sup1}$ | $\varphi_o^{Sup2}$ | $\varphi_o^{Man1}$ | $\varphi_o^{Man2}$ | $\varphi_o^{Man3}$ | $\varphi_o^{Tra1}$ | $\varphi_o^{Tra2}$ | $\varphi_o^{Dis1}$ | $\varphi_o^{Dis2}$ | $\varphi_o^{Dis3}$ | $\varphi_o^{Dis4}$ | $\varphi_o^{Cus1}$ | $\varphi_o^{Cus2}$ | $\varphi_o^{Cus3}$ | $\varphi_o^{Cus4}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.75 | 1 | 0.39 | 0.50 | 1 | 1 | 0.18 | 1 | 0.14 | 1 | 0.41 | 1 | 0.91 | 1 | 1 | 1 |
| 2 | 0.69 | 1 | 0.73 | 0.01 | 0 | 1 | 0.58 | 0.36 | 1 | 0.45 | 1 | 1 | 0.92 | 0.86 | 1 | 0.82 |
| 3 | 0.83 | 0.66 | 0.75 | 1 | 0.30 | 1 | 1 | 0.10 | 0.46 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 4 | 0.77 | 1 | 1 | 1 | 1 | 0.55 | 0.43 | 0.30 | 1 | 1 | 1 | 0.20 | 0.82 | 0.79 | 0.93 | 0.82 |
| 5 | 0.84 | 0.67 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.58 | 0.62 | 0.46 | 0.54 |
| 6 | 0.82 | 0.99 | 0.64 | 1 | 1 | 1 | 0.15 | 1 | 0.46 | 1 | 1 | 1 | 0.91 | 0.91 | 0.98 | 1 |
| 7 | 0.90 | 0.72 | 1 | 1 | 1 | 1 | 1 | 0.32 | 1.13 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 8 | 0.73 | 1 | 1 | 1 | 1 | 0.66 | 0.14 | 0.05 | 0.04 | 0.39 | 1 | 0.65 | 1 | 1 | 1 | 1 |
| 9 | 0.65 | 1 | 1 | 1 | 1 | 0.82 | 0.50 | 0.04 | 0.14 | 1 | 0.34 | 0.64 | 0.61 | 066 | 0.38 | 0.46 |
| 10 | 0.68 | 0.63 | 1 | 1 | 1 | 1 | 0.18 | 1 | 0.57 | 0.44 | 1 | 0.65 | 0.60 | 0.58 | 0.44 | 0.61 |

Looking horizontally at the same table, it is possible to see, for each supply chain, the number of efficient divisions. As expected, DMU 7 has the highest efficiency score and the highest number of efficient divisions (12/15) while DMU 9 has the worst efficiency score and the worst number of efficient divisions (5/15). As an illustration, we consider the seventh supply chain (DMU7).

As the second column of Table 24 shows, the efficiency score is $\theta$ = 0.90 and this DMU has 12 efficient divisions, while divisions 1, 7 and 8 are inefficient (0.72, 0.32, 0.13, respectively). It is possible to compute the values that will render efficient this DMU. In particular, the undesirable output of oil field (gas flaring) could be reduced to 0.72 (756) = 544.32, the undesirable output of the second transmitter could decrease from 61.92 to 61.92 (0.32) = 19.81 and the undesirable output of the first distributor could reduce from 13.6 to 0.13 (13.6) = 1.77.

Besides, we consider the results of slack variables in the intermediate measures, S (1,3) = − 836.28.

S (1,4) = 1948.21, S (1,5) = 5931.98. These values highlight that, for improving the efficiency score, the intermediate measures sent from the oil field of supply chain 7 (DMU7) to manufacturer 1 should decrease, while this measure should increase towards the second and third manufacturers. Looking at the slack variables S (3,7) = 0, S (4,7) = 1791.04 and S (5,7) = 660.63, for DMU7 it can be observed that electricity flows from manufacturers 2 and 3 sent to the second transmitter can increase by 1791.04 and 660.63 106 kwh, respectively. As concerning slack variables related to the connection between transmitters and distribution companies, the only inefficiency is obtained from the first transmitter to the first distributer (S (6,8) = − 8967.26) , the other slack variables are null.

Finally, looking at slack variables of intermediate measures between distributors and customers, all the quantities from distributer 1 to the different final consumers have to be increased (S (8,12) = 3048.87, S (8,13) = 1614.11, S (8,14) = 1345.09, S (8,15) = 2959.20).

A similar analysis can be put forward to the remaining supply chains. According to the results of the slack variable in the inputs constraints this value shows that for improving the efficiency score , the first input of the oil field in supply chain 7 (DMU7) should decrease from 46800 to 27244.737.

Looking at the slack variables for DMU7, $S_1^-$ (8) =199.54, $S_2^-$ (8) = 11297.82. It can be seen that the first input of distributer 1 should decrease from 3639 to 3439.446 and the second input should decline from 37153 to 25855.180, the other slack variables in input constraints are null. Specially, we consider the results of variables $\lambda$ and $\mu$ in supply chain 7(DMU7) as follows:

$\mu(1, 2) = 0.025$, $\mu(7, 2) = 0.482$, $\mu(8, 5) = 0.757$, $\lambda(1,2) = 0.975$, $\mu(7,2) = 0.482$, $\lambda(8,5) = 0.243$.

These values shows that, for improving the efficiency score, the first supplier (oil field) and the second transmitter inputs of supply chain 2 (DMU2) are utilized for cleaning up flaring gas and decline loose of power in supply chain 7 (DMU7).As similar the first distributer active level of supply chain 5 (DMU5) scaling down to decrease undesirable outputs while the other undesirable outputs have remained active in the supply chain (DMU7).

Let us now try to detect the determinants of the success of supply chain 7 (DMU7) in terms of efficiency. DMU7 presents the higher penetration level of RES concerning the other DMUs.

Approximately, supply chain 7 comprises 43% power plants operated by renewable technology. In particular, this DMU contains 29% wind, solar and 14% hydropower plants that produce a considerably amount of electricity in production processes without pollution emission. The use of renewable plants limits the needs of fossil fuels like gas and diesel and limits greenhouse gas emissions.

It is worth mentioning that supply chain 7 as the best performing unit has the most renewable power plants, while supply chain number 5 belongs to the second-highest efficiency score contain 25% solar, and wind power plants, the other hand supply chain number 5 has the number conventional power plants consume fuel oil, natural gas and diesel more than DMU number 7, therefore supply chain number 5 produce huge amount of air pollutants such as sulfur oxides, nitrogen oxides and carbon dioxides. As illustration, we consider the ninth supply chain (DMU9). According to Table 24 supply chain number 9 is the worst performing unit with efficiency score $\theta = 0.65$ and this supply chain has seven power plants: one of them utilizes hydro technology and one power plant operates with renewable technology while the other power plants consume fossil fuels to produce electricity. More in detail, supply chain 9 includes 14% of wind, solar and 14% of hydropower plants, but power plants produce minimal intermediate measures in different divisions while the rest is composed of nonrenewable plants with high emission levels.

Now we investigate what factors inspire the highest efficiency score in supply chain number 7 (DMU7). Indeed, it is important to know which factors effect on efficiency score specifically, we are interested in knowing which indexes play an important role in the most efficient of the supply chain. According to table 23 DMU7 comprise 80% efficient divisions .the second supplier (gas field), all of the manufacture (power plants) ,the first transmitter, the second, third and fourth distributer and customers of residential, public, agriculture and industry divisions are efficient in supply chain 7. Firstly, the gas field of supply 7 transfer approximately 60% average annual production of gas to power plants to electricity production and power plants transmit about 63% annual maximum capacity to regional power companies.

Secondly, undesirable outputs of manufacture number1 have the least amount of pollution emissions of $NO_X$, $SO_X$ and $CO_2$ gases between 10 supply chains. As concerning distributers capacity, the least capacity of distribution line in 10 supply chains belongs to second and third distribution companies in supply chain 7 (DMU7) and desirable outputs in residential, public and Agriculture divisions contain the most amount in the whole of supply chains. Thirdly, amount of oil and gas transmit to the third power plant, the electricity sent to the first transmitter and electricity dispatch to the residential division has the most measure in all of the supply chains.

Finally, according to Table 24, the first column shows the weights of entities to supply chains. The most weights of entities have been assigned to customer, manufacture, transmitter and supplier divisions respectively, therefore customer divisions have a fundamental role to distinguish the most efficient supply chain. Accordingly, if the supply chain wants to obtain the highest efficiency, it should pay attention noticeable to customer and manufacture divisions.

According to the model proposed in Section 4, a further analysis has been conducted by considering a non-cooperative network in which each member of each stage is evaluated separately by model (8). After finding the efficiency scores of each division of the network, the efficiency of each DMU is computed as a weighted average of the efficiency scores of each division by (9) equation. It has been proved that this second methodology has lower efficiency scores than the previous one (for proof see [21]). In Table 25 the results of this second analysis have been reported.

**Table 25.** The non-cooperative efficiency scores of the considered supply chains (DMUs).

| DMU | $\phi_o^{h_S}$ | $\phi_o^{Sup1}$ | $\phi_o^{Sup2}$ | $\phi_o^{Man1}$ | $\phi_o^{Man2}$ | $\phi_o^{Man3}$ | $\varphi_o^{Tra1}$ | $\phi_o^{Tra2}$ | $\phi_o^{Dis1}$ | $\phi_o^{Dis2}$ | $\phi_o^{Dis3}$ | $\phi_o^{Dis4}$ | $\phi_o^{Cus1}$ | $\phi_o^{Cus2}$ | $\phi_o^{Cus3}$ | $\phi_o^{Cus}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.73 | 1 | 0.39 | 0.50 | 1 | 1 | 0.17 | 1 | 0.14 | 0.57 | 0.41 | 1 | 0.91 | 1 | 1 | 1 |
| 2 | 0.67 | 1 | 0.73 | 0.01 | 0 | 1 | 0.58 | 0.36 | 1 | 0.63 | 1 | 1 | 0.92 | 0.86 | 1 | 0.82 |
| 3 | 0.82 | 0.66 | 0.75 | 1 | 0.30 | 1 | 1 | 0.10 | 0.46 | 0.73 | 1 | 1 | 1 | 1 | 1 | 1 |
| 4 | 0.76 | 1 | 1 | 1 | 1 | 0.55 | 0.43 | 0.30 | 1 | 0.69 | 1 | 0.20 | 0.82 | 0.79 | 0.92 | 0.82 |
| 5 | 0.84 | 0.67 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.96 | 1 | 1 | 0.58 | 0.62 | 0.45 | 0.54 |
| 6 | 0.82 | 0.98 | 0.64 | 1 | 1 | 1 | 0.15 | 1 | 0.46 | 0.74 | 1 | 1 | 0.91 | 0.91 | 0.98 | 1 |
| 7 | 0.89 | 0.72 | 1 | 1 | 1 | 1 | 1 | 0.32 | 1.13 | 0.81 | 1 | 1 | 1 | 1 | 1 | 1 |
| 8 | 0.73 | 1 | 1 | 1 | 1 | 0.66 | 0.14 | 0.05 | 0.35 | 0.46 | 1 | 0.65 | 1 | 1 | 1 | 1 |
| 9 | 0.62 | 1 | 1 | 1 | 1 | 0.82 | 0.50 | 0.03 | 0.14 | 0.51 | 0.34 | 0.65 | 0.61 | 066 | 0.38 | 0.46 |
| 10 | 0.68 | 0.63 | 1 | 1 | 1 | 1 | 0.18 | 1 | 0.57 | 0.39 | 1 | 0.65 | 0.60 | 0.57 | 0.44 | 0.61 |

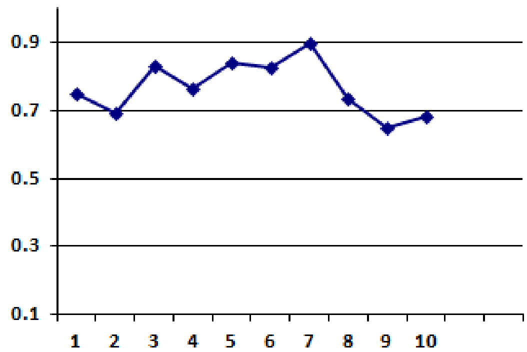


**Figure 3.** The overall efficiency scores for 10 supply chain.

Looking at Table 25, it can be easily checked that the ranking between the 10 supply chains remain unchanged, even if the efficiency scores are slightly lower. It can be noticed that DMU6 and DMU3 in the non-cooperative model have the same efficiency scores. Nevertheless, looking at the efficiency scores of the divisions, DMU6 has 7/15 efficient divisions while DMU3 has 9/15 efficient divisions. In comparison with the overall model, the non-cooperative model can have a more discriminative power concerning the single divisions but a less discriminative on concerning the overall efficiency score. Similar results can be observed by comparing DMU1 and DMU8. Figure 3, present the efficiency scores measured by the overall model of supply chains DMU 10.

## 6. Conclusions

An appropriate performance measurement system is an important requirement for the effective management of a supply chain. To achieve this, the performance evaluation of the entire supply chain is extremely important. This means utilizing the combined resource of the supply chain members in the most efficient way helps to provide competitive and cost-effective products and services. Recently several studies have employed DEA approaches for incorporating undesirable outputs into efficiency and productivity change analysis. This model presents both the overall efficiency score of a supply chain and individual efficiency score of its partners at the same time taking into account undesirable outputs under a week disposability assumption. The proposed multi-stage DEA approach could evaluate the efficiency of a sustainable supply chain when there is an arbitrary number of supplier, manufacturer, transmitter, distributor and customers as each stage have unequal weights. Also, the proposed model can enable decision- makers to simultaneously minimize environmental harmful impact and maximize operational performance while meeting customers' satisfaction. In particular, this study proposed an approach to sustainability assessment of supply chain which the first priority was environmental performance and the second priority was operational performance. Meanwhile, the two issues of privatization and competition in power industry sectors play an important role in global markets. As an application, this study analyzes the behavior of the Iranian power industry by subdividing the industry into different regions (each region represents a supply chain or DMU) and measures the performance of these regions by considering their electricity utilization and environmental protections. Some insights can be obtained from the analysis to improve the performance and in particular new investments in clean technologies could reduce the undesirable outputs that affect the performance of the different supply chains.

The proposed approach has methodological limitations in leading environmental performance assessment. 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 .The problem considered in this study needs to the further researches in future. Similarity, this study can be conducted for green supply chain management evaluation in the presence of dual-role factors and non-discretionary factors.

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