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Research Article

Green Productivity in Iran's Thermal Power Plants: The Malmquist-Luenberger Approach

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Abstract:
Electricity generation in thermal power plants as the largest producer of electricity in Iran is associated with greenhouse gas emissions. In this paper, using the Malmquist-Luenberger method, green productivity, and efficiency changes are measured for 31 thermal power plants (including 12 steam power plants, 13 gas power plants, and six combined cycle power plants) during 2009-2016. The results show a slight increase in green productivity in gas power plants and a slight reduction in green productivity in combined cycle power plants. Also, green productivity in steam power plants has not changed approximately. The mean values of the Malmquist-Luenberger index for these three types of power plants are 1.007, 0.997, and 1.0005, respectively. Although the environmental performance of gas power plants is slightly better than the two other types of power plants, but the difference of mean values of the Malmquist-Luenberger index for the three types of power plants is small.Furthermore, if we compare the power plants individually, we get different results, the highest and lowest mean values of the Malmquist-Luenberger index (1.06 and 0.982) is for a steam power plant (Shahid Mofateh) and a gas power plant (Konarak) respectively. Therefore, the power generation method and type of power plant (gas, steam and combined cycle) have no significant effect on the environmental performance of power plants and the environmental performance of them can be affected by other factors. The type of fuel consumed by power plants is one of the most critical factors affecting the green productivity of power plants. Over the past two decades, many countries have replaced natural gas with coal to reduce greenhouse gas emissions. Hence the abundance of natural gas resources in the country is one of the advantages of thermal power generation taking into account environmental considerations. Another point is that Iran has planned to convert the significant number of gas plants to combined cycle power plants. The research findings support this policy because the results show that combined cycle power plants are more efficient than gas power plants.

Keywords: Efficiency, Green Productivity, Thermal Power Plants, Malmquist-Luenberger Method

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Introduction:

Human efforts in the second half of the twentieth century to increase living standards by following the traditional patterns of economic growth and increasing production, while the world experienced rapid population growth, increased the excessive withdrawal of natural resources and resulted in a significant increase in environmental pollutants. The continuation of this situation led to concerns about the degradation of the environment as the place of human life, and provided the basis for the formation of the concept of "sustainable development."

In 1987, the World Commission on the Environment and Development for the first time in a report entitled “Brandt land report”, defined sustainable development as follow: Sustainable development is a development that meets the needs of the present, without threatening the ability of future generations to meet their needs. Many industrial companies, with an emphasis on sustainable development, are struggling to maintain sustainability by adopting new strategies. They pursue pollution control approaches in line with their social responsibility (Gidding et al., 2002). In sustainable development for measuring productivity, in addition to economic considerations, environmental impacts are also taken into account and emphasize the concept of 'green productivity'. The goal of green productivity is to achieve a higher level of productivity to meet the needs and simultaneously to maintain and improve the environment. Green productivity encourages business activities to be more competitive, innovative, and responsive to the environment. (Tak Hur,2004).In the green productivity approach, goods and services are priced competitively to meet community needs and not only raise the quality of life, but also reduce the environmental impact of goods and reduce the resources intensity throughout the life cycle to a minimum level. The environmental effects were first calculated by Schaltegger and Sturm (1990) for calculating efficiency. They expanded the concept of “economic and ecological efficiency (eco-efficiency)" and also presented an indicator for measuring it: Eco-efficiency= (Economic value created)/ (Environmental effects)

Sustainable development requires access to energy resources that are accessible to all, economically feasible, and environmentally clean. In this regard, electricity has a special place both in terms of production and consumption. In 2017, 85.33 percent of the world's population and 99.44 percent of Iran's population had access to electricity.

Table 1. Share of different sources of power generation in Iran and the world (2017)

	Oil resources Coal and gas	Oil resources	Coal	Nuclear power	Hydropower	Other renewable resources (Except hydroelectric power)
world	66.34	4.09	40.66	10.62	16.21	5.97
Iran	93.17	21.66	0.19	1.62	5.04	0.14

source: data.worldbank.org

As the data show, the share of new energies, hydroelectric and nuclear power is still low in world electricity production, especially in Iran and oil, gas and coal are the most important sources of electricity production, with the difference that at the global level, coal and in Iran, gas has ranked first in electricity generation. The high share of fossil resources in electricity production, emphasizes the need to pay attention to green productivity in thermal power plants as the most important source of electricity generation in order to achieve sustainable development. In the process of generating electricity in thermal power plants, there is always a large number of greenhouse gases that have harmful effects on the environment and reduce green productivity in this industry. For example, in the United States in 2017, the electricity generation industry, with a 29% share of total CO2 emissions, is the most important source of CO2 emissions in the country (US Environmental Protection Agency, 2017). According to World Bank data in 2017, Iran has been ranked seventh in the world and first in the Middle East region in the production of co2 with 649481 kt production, among which the amount of CO2 emissions in the electricity generation industry is significant. In 2016, Iran was ranked 9th in the world's largest thermal power producers, and in 2018, thermal power plants accounted for 92.2 percent of the country's total electricity generation (www.tpph.ir). Therefore, measurement of productivity with consideration of environmental impacts in electricity production, especially in thermal power plants, as the most important source of electricity generation, is essential. The present paper seeks to measure productivity changes and green productivity in Iran's thermal power plants (including 12 steam power plants, 13 gas power plants, and six combined power plants) in the period of 2009-2016.

Literature review

Kumar (2019), measured carbon-sensitive efficiency and productivity growth in technologically heterogeneous coal-fired thermal power plants in India, from 2000 to 2013, using difference-based Luenberger Productivity Indicator (LPI). The thermal power plants are grouped into two categories: the central sector and the state sector. Findings show that the state sector plants have a higher potential to simultaneously increase electricity generation and reduce carbon emission than the central sector plants. Zhu et al. (2019), evaluate the electricity product efficiency of various provinces in China, based on the data envelope analysis (DEA), from 2005 to 2014. Results show that China's regional power production efficiency has a significant difference between coastal developed and inland areas. The dynamic evaluation further proved that the difference is mainly due to technological change. Song et al. (2018), measured the productivity of Chinese thermal industries in 30 Chinese provinces from 2006 to 2013, using DEA and GMLP index. The results reveal that the development of the Chinese thermal power industry varies significantly in different regions, and it is highly correlated with the level of local economic development.

Emami et al. (2017) evaluated the technical efficiency and bio-efficiency of 16 selected thermal power plants of Iran during the period 2011-2015 using the DEA method based on the output-driven model. A review of the average bio-efficiency of these plants during the period showed that the efficiency was between 85.7 and 90.1%. The MLP index shows that the environmental productivity values of power plants have fluctuated over the last five years, but eventually increased. Chen and Golley(2014), investigate changing patterns of 'green' total factor productivity growth of 38 Chinese industrial sectors during the period 1980–2010 using Directional Distance Function (DDF) and the MLP Index. Findings indicate that the Chinese industry is not yet on the path towards sustainable, low-carbon growth. Zang and Choi (2013) compare the changes in CO_2 emissions in fossil fuel power plants in China and Korea over the years 2005-2010. The results show that Korean power plants have more capacity for innovation, while Chinese power plants have a higher ability to take technological leadership. Zang et al. (2013) assessed the productivity and production of Co_2 in Korean thermal power plants in a model called Global Malmquist–Luenberger. The results show that the performance of coal power plants in terms of total energy efficiency and CO_2 emissions is higher than that of oil power plants. In comparing the technology boundary, oil power plants have more technology gap. Fathollah Zadeh Aghdam (2011) examines the dynamics of productivity changes in the Australian electricity industry using the MLP index, and suggests that productivity in this industry is mainly due to technology upgrades and regular adjustments, public participation and Privatization has played a smaller role. Kargari and Mastouri (2010) compared greenhouse gas emissions at Iran's power plant using the Life Cycle Assessment Method (LCA). The results show that thermal power plants have the highest life cycle emissions (CO_2 emissions per kWh), and the lowest emissions are for hydroelectric power plants and nuclear power plants. Also, among the thermal power plants, gas power plants have the lowest greenhouse gas emissions Sueyoshi et al. (2010) presented a new approach to data envelopment analysis to evaluate the environmental and operational performance of coal-fired power plants under the Clean Air Act of the United States. The results showed that the Clean Air Act is increasingly effective in environmental consistency, and managers need to balance the environmental performance and operational efficiency.

Barros and Peypoch (2008) firstly ranked Portugal's thermal power plants according to the relative technical efficiency using the DEA method, and then, using the proposed method by Simar and Wilson (2007), examined the factors affecting the technical efficiency of the power plants. The results show that the life of the power plant, the amount of fossil fuel consumption, and pollution have a negative impact on the technical efficiency of the plant, and the contribution of the power plant to the electricity market has a positive and significant impact. Nakano and Manaji (2008) examined the impact of regulatory reforms on the efficiency of steam power plants in Japan by measuring the Malmquist–Luenberger productivity index in the period 1978-2003 and showed that these reforms had an impact on productivity improvement.

Aboonori and Lajevardi (2013), examined the impact of the formation of Iran's electricity market on the efficiency of power plants using the DEA method and the Malmquist–Luenberger productivity index in the period 2002- 2009. The results indicate that the formation of the electricity market efficiency has a positive effect on the steam power plants and a negative effect on the combined cycle and gas power plants. Seifi et al. (2013) calculate the environmental efficiency of the electricity industry using data from thermal power plants in Khorasan provinces during the years 2005-2008. The results show that the environmental efficiency of these plants is, on average, 93.81 percent. Imami Meybodi, Afghah, and Rahmani (2009) measured the technical efficiency of 26 existing power plants in Iran in 2007 as well as productivity during the years 2002 to 2007 using the data analysis and Malmquist index. The results of the research showed that the average technical efficiency of the power plants under the assumption of constant and variable returns in 2007 was 76.4 and 92.8 percent, respectively, and the inefficiency of the scale had the most effect on technical inefficiency. The growth of the productivity of all power plants during the studied years was an average of 1.5%, and the most effective factor in the changes in productivity is technological changes.

Previous studies of green productivity in Iranian power plants have not investigated the impact of power generation method (i.e., type of power plant) on the environmental performance of power plants. Also, to the best of my knowledge, similar studies have not been done in other countries. The present study measure green productivity and efficiency changes for each type of Iranian thermal power plants (including 12 steam power plants, 13 gas power plants and six combined cycle power plants) during 2013-2016 individually and then answer the question of which type of these power plants have performed better in promoting green productivity in order to achieve sustainable development. In other words, consider whether the power generation method (i.e., gas power plants, steam power plants, and combined cycle power plants) affects the green productivity of power plants.

Method and data

This study was carried out using the data of 56 Iranian power plants (including 12 steam power plants, 13 gas power plants, six combined cycle power plants, and 25 hydroelectric power plants) in 2009-2014 and applying Malmquist-Luenberger index to calculate and analyze the efficiency and green productivity of these power plants. The data were all extracted from the website of the Thermal Power Plant Holding (www.tpph.ir) and Tavanir (amar.tavanir.org.ir). R software is also used in this article. Each power plant has inputs and produces outputs. Therefore, in a general way, the variables that affect the performance of power plants can be considered as input and output categories. Besides, outputs may not always be positive, and sometimes there will be negative outputs.

Inputs:

Operating Capacity (in MWh) =nominal capacity * Percentage of exploitation of the plant's capacity

Fuel Consumption in (kilocalories) = (Fuel consumed * Thermal value)

Outputs:

Desired output = Power generation (in megawatt-hours)

Unfavorable Output = greenhouse gas emissions, including co2 and so2 (in tons)

The Malmquist index

The Malmquist Index was first introduced by Malmquist (1953), and By Caves et al. (1982), Malmquist this Index was expanded. By Farr (1994), the data envelopment analysis method was used to measure the total productivity of production factors using the Malmquist Index. This index has significant features. Its calculation, unlike other important indicators of measuring the total factor productivity, does not need to have information about the price of the factors of production and product, which sometimes it is difficult to collect or impossible. Using the index does not require any behavioral assumptions, such as maximizing profits or minimizing costs. However, the attractive feature of this index is to analyze the effect of changes in technical efficiency and the effect of technological change (Hakim pour and Avazalipour2012). The mathematical model of the Malmquist index is defined based on the distance function, where the change in the total factor productivity between the two points of the data is measured by calculating the ratio of the distance between each of these points from the level of a given technology.

Malmquist index = change in efficiency * technology change

In the following diagram, for each period, a simple production technology, including an input (x) and an output (y), is shown assuming a constant return to scale.

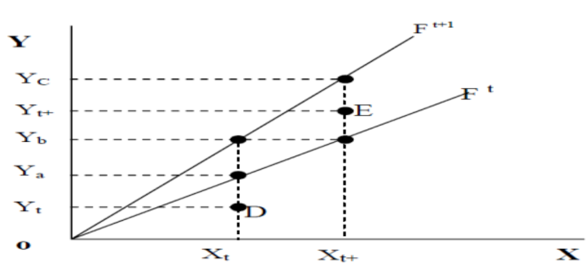


Figure 1. The Malmquist index and its components (Hakimipour and Avazalipour, 2012)

In the graph above, the two functions Ft and Ft+1 represent the production frontiers, respectively, at time t and t + 1. If the firm produces in these two periods at D and E respectively, then in each period, it will operate at a lower level than its production frontier and will face the problem of inefficiency in both periods. In such a situation, according to the above figure, the values of change in technical efficiency and technology change between the two periods (t and t+1) will be as follow (Coelli et al., 1998):

$$change\ in\ technical\ effeciency = \frac{y_{t+1}/y_c}{y_{t+1}/y_a} \tag{1}$$

$$technological\ change = \left[\frac{y_{t+1}/y_b}{y_t/y_c}.\frac{y_t/y_a}{y_t/y_b}\right]^{\frac{1}{2}} \tag{2}$$

Changes in total factors productivity during the two periods are also obtained from the multiplication of the above two relations:

$$M_0(x_t.y_t.x_{t+1}.y_{t+1}) = \frac{y_{t+1}/y_c}{y_t/y_a}\cdot\left[\frac{y_{t+1}/y_b}{y_{t+1}/y_c}\cdot\frac{y_t/y_a}{y_t/y_b}\right]^{\frac{1}{2}} \tag{3}$$

This index includes data about the desired inputs and outputs, and the undesirable output is not considered; hence, green productivity is ignored in this index.

Malmquist -Leuenberger Index

The Malmquist -Leuenberger productivity (MLP) index is constructed in a similar way to the traditional Malmquist index. The main difference, of course, is that the Malmquist -Leuenberger Index uses the directional distance function and the other from the “Shepard's method” for formulation. Unlike the Malmquist index, this index takes into account the adverse effects of production, namely pollution, as an outflow. According to Chang et al. (1997), The Malmquist -Leuenberger productivity index is defined as follow:

Suppose that k has a thermal power plant in which each power plant has an input X=(x_1,…x_N) ε R_+^N to produce the desired output y=(y_1,…y_M) ε R_+^M and undesirable output b=(b_1,…b_j) εR_+^J . The environmental production function for time t is defined as follows (Kumar, 2006):

$$p_t(x) = \{(y_t.b_t):\ x_t\ can\ produce\ \ (y_t.b_t)\}$$

$$ML_t^{t+1} = \left[\frac{\left(1+\overrightarrow{D_0^{t+1}}(x^t.y^t.b^t;y^t.-b^t)\right)}{\left(1+\overrightarrow{D_0^{t+1}}(x^{t+1}.y^{t+1}.b^{t+1};y^{t+1}.-b^{t+1})\right)} \times \frac{\left(1+\overrightarrow{D_0^{t}}(x^t.y^t.b^t;y^t.-b^t)\right)}{(1+\overrightarrow{D_0^{t}}(x^{t+1}.y^{t+1}.b^{t+1};y^{t+1}.-b^{t+1}))}\right]^{1/2} \tag{4}$$

Which can be defined by the following components:

$$MLEFFCH_t^{t+1} = \frac{1+\overrightarrow{D_0^t}(x^t.y^t.b^t;y^t.-b^t)}{1+\overrightarrow{D_0^{t+1}}(x^{t+1}.y^{t+1}.b^{t+1};y^{t+1}.-b^{t+1})} \tag{5}$$

$$MLTECH_t^{t+1} = [\frac{\left(1+\overrightarrow{D_0^{t+1}}(x^t.y^t.b^t;y^t.-b^t)\right)}{\left(1+\overrightarrow{D_0^t}(x^t.y^t.b^t;y^t.-b^t)\right)} \times \frac{\left(1+\overrightarrow{D_0^{t+1}}(x^{t+1}.y^{t+1}.b^{t+1};y^{t+1}.-b^{t+1})\right)}{(1+\overrightarrow{D_0^t}(x^{t+1}.y^{t+1}.b^{t+1};y^{t+1}.-b^{t+1}))}]^{1/2} \tag{6}$$

- Relationships 1 and 3 compute the geometric mean of the results using the period t and period t + 1 as reference technology.
- MLEFFCH (Malmquist-luenberger efficiency change), calculates the output efficiency changes between the two periods.
- MLTECH (Malmquist-luenberger technical change), measures technical changes.
- The productivity progression with $ML_t^{t+1} > 1$is shown and its decrease with $ML_t^{t+1} < 1$ is shown.
- In the relation (2), the index $MLEFFCH_t^{t+1}$ shows the distance of the observation with their boundaries in the time interval t and t + 1. If ($MLEFFCH_t^{t+1} > 1$), then the observation is closer to the boundary at the t + 1. If ($MLEFFCH_t^{t+1} < 1$), it means that it is farther away at the t + 1.
- In the relation (3), the index $MLTECH_t^{t+1}$ measures the technical changes in producing good and bad outputs. ($MLTECH_t^{t+1} > 1$) Indicates the technical progress and ($MLTECH_t^{t+1} < 1$) indicates a technical regression.

Calculation of directional distance function

Directional distance function can be calculated as linear programming solutions. You must solve 4 problems for each observation. The two problems are solved with respect to the fact that all observations are similar in time. For example, observation k' at interval t:

$$\begin{aligned} &\{\overrightarrow{D_0^t}(x^{t.k'}.y^{t.k'}.b^{t.k'};y^{t.k'}.-b^{t.k'}) = \max \beta \\ &s.t. \sum_{k=1}^{K} z_k^t y_{mk}^t \geq (1+\beta) y_{mk'}^t \\ &\qquad m = 1.\dots.M \\ &\sum_{k=1}^{K} z_k^t b_{ik}^t = (1-\beta) b_{ik'}^t \qquad i = 1.\dots.I \\ &\sum_{k=1}^{K} z_k^t x_{nk}^t \leq x_{nk'}^t \qquad n = 1.\dots.N \\ &z_k^t \geq \qquad k = 1.\dots.K \end{aligned} \tag{7}$$

Two other problems have combined times. For example, the of directional distance function for observation k' in the period t + 1, using the technology of period t, can be calculated through the following linear programming solution:

$$\overrightarrow{D_o^t}(x^{t+1.k'}.y^{t+1.k'}.b^{t+1.k'};y^{t+1.k'}.-b^{t+1.k'}) = \max\beta \tag{8}$$

$$s.t.\sum_{k=1}^{K} z_k^t y_{mk}^t \geq (1+\beta) y_{mk'}^{t+1} \qquad m = 1.\dots.M$$

$$\sum_{k=1}^{K} z_k^t b_{ik}^t = (1-\beta) b_{ik'}^{t+1} \qquad i = 1.\dots.I$$

$$\sum_{k=1}^{K} z_k^t x_{nk}^t \leq x_{nk'}^{t+1} \qquad n = 1.\dots.N$$

$$z_k^t \geq \qquad k = 1.\dots.K$$

Results and Discussions

The results of calculating the Malmquist -Leuenberger index for steam, gas, and combined-cycle power plants are presented in Tables (2), (3), and (4), respectively.

Table 2. The Malmquist -Leuenberger Index in Iranian steam power plants

Power Plant	The Malmquist -Leuenberger Index			Efficiency Change			Technical Change		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Besat(Tehran)	0.995	1.060	0.935	0.992	1.033	0.9654	1.004	1.094	0.905
Isfahan(Islamabad)	0.996	1.013	0.982	1.001	1.072	0.933	0.997	1.057	0.945
Shahid Beheshti(Lushan)	1.008	1.074	0.935	1.000	1.000	1.000	1.0008	1.074	0.935
Shahid Salimi (Neka)	1.002	1.021	0.983	1.001	1.061	0.945	1.002	1.076	0.947
Ramin(Ahvaz)	0.993	1.064	0.924	0.991	1.023	0.957	1.001	1.039	0.965
Bandar Abbas	0.997	1.049	0.951	1.001	1.045	1.000	0.996	1.044	0.951
Shahid Rajai(Qazvin)	1.003	1.047	0.970	1.000	1.000	1.000	1.003	1.047	0.970
Bistoon(Kermanshah)	1.004	1.029	0.965	1.001	1.023	0.977	1.004	1.048	0.965
Shahid Mofateh (Hamedan)	1.069	1.100	0.943	1.019	1.102	0.907	1.005	1.040	0.970
Iranshahr	1.009	1.051	0.953	1.0000	1.000	1.000	1.000	1.051	0.953
Shazand(Arak)	0.997	1.044	0.941	0.995	1.013	0.979	1.001	1.044	0.961
Sahand(Bonab)	1.0070	1.095	0.946	1.000	1.009	1.000	1.007	1.095	0.946
Total	1.0005	1.100	0.924	0.997	1.102	0.907	1.002	1.095	0.905

As shown in Table (2), the mean of The Malmquist -Leuenberger Index in steam power plants during the study period is 1.0005, which is very slightly different from one, indicating no change in green productivity in these plants. Also, based on these results, the average efficiency change is less than 1, which indicates a decrease in efficiency in steam power plants, but the average of technical change is greater than one, which indicates technical progress in these power plants. The highest amount for green productivity, the efficiency change, and the technical change are related to Shahid Beheshti, Shahid Mofateh, and Sahand power plant, respectively.

Table 3. The Malmquist -Leuenberger Index in Iranian gas power plants

Power Plant	The Malmquist -Leuenberger Index			Efficiency Change			Technical Change		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Shiraz	1.010	0.936	1.068	1.015	0.957	1.065	0.996	0.933	1.067
Bushehr	0.999	0.874	1.110	0.985	0.887	1.095	1.016	0.911	1.070
Shahid Beheshti(Lushan)	0.999	0.803	1.238	1.003	0.878	1.138	0.991	0.903	1.087
Dorud	1.038	0.959	1.148	1.016	0.976	1.060	1.021	0.951	1.093
Rey	1.009	0.873	1.156	1.012	0.944	1.075	0.994	0.925	1.075
Konarak(Chabahar)	0.982	0.949	1.015	1	1	1	0.982	0.949	1.015
Sofiyan(Tabriz)	1.0006	0.927	1.079	1.014	0.978	1.053	0.986	0.915	1.080
Zahedan	0.982	0.951	1.039	1.001	0.969	1.031	0.982	0.951	1.007
Ghaen	0.996	0.814	1.164	0.995	0.848	1.096	0.999	0.931	1.062
Hasa	1.002	0.8876	1.083	1.005	0.951	1.050	0.996	0.910	1.064
Kangan	1.010	0.931	1.064	1.012	0.896	1.157	1.002	0.902	1.092
Yazd	1.019	0.861	1.164	1.008	0.918	1.084	1.007	0.929	1.074
Bandar Abbas	1.046	0.910	1.220	1.028	0.957	1.114	1.014	0.934	1.095
Total	1.007	0.803	1.238	1.007	0.848	1.157	0.99935	0.902	1.0953

According to the results presented in Table (3), the mean of The Malmquist-Leuenberger Index in gas power plants during the study period is 1.007, which indicates a slight increase in green productivity in these power plants. Also, the average of the efficiency changes is greater than 1, which indicates an increase in efficiency in Iranian gas power plants. The highest amount for the green productivity and the efficiency change are related to Bandar Abbas power plant, and the highest amount for the technical change is related to the Dorud power plant.

Table (4) presents the mean of the Malmquist-Leuenberger index in the combined cycle power plants of Iran. In this table, the average of the Malmquist -Leuenberger index is slightly smaller than one, indicating a slight decline in green productivity in these power plants. The results also show an increase in efficiency and a decrease in technical progress at these plants.

Overall,Shahid Mofteh, Yazd, and Bandar Abbas power plants have the highest green productivity with the Malmquist -Leuenberger Index of 1,069, 1,046, and 1,038, respectively and Hormozgan, Zahedan and Konarak power plants have the lowest green productivity index with 0.985. , 0.982 and 0.982, respectively.

Table 4. The Malmquist -Leuenberger Index in Iranian combined-cycle power plants

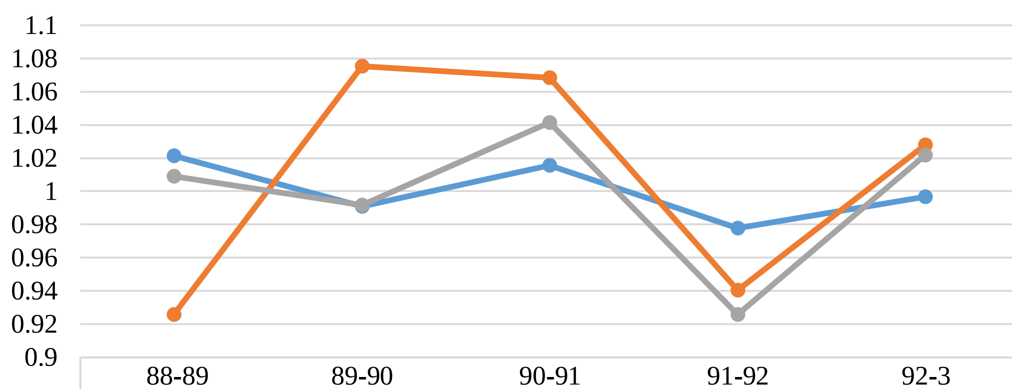
Power Plant	The Malmquist - Leuenberger Index			Efficiency Change			Technical Change		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Shahid Rajaee	1.002	0.941	1.035	1.007	0.939	1.071	0.997	0.878	1.092
Shahid Salimi	0.996	0.861	1.114	1.016	1	1.083	0.979	0.861	1.114
Yazd	1.006	0.906	1.081	1.016	0.964	1.081	0.992	0.874	1.099
Kerman	1.008	0.879	1.084	1.011	0.983	1.064	0.996	0.894	1.084
Hormozgan	0.985	0.839	1.173	1.001	0.803	1.244	0.990	0.943	1.044
Shirvan	0.987	0.907	1.140	0.999	0.923	1.072	0.987	0.907	1.062
Total	0.997	0.8396	1.173	1.008	0.8038	1.2440	0.9906	0.86153	1.114

The summary of the results of the Malmquist-Leuenberger Index, efficiency change, and technical change for different power plants are presented in the table below.

Table 5. The Malmquist-Leuenberger Index in Iranian thermal power plants

Power Plants	The Malmquist - Leuenberger Index	Efficiency Change	Technical Change
Steam power plants	1.0005	0.997	1.002
Gas power plants	1.007	1.0075	0.99935
Combined-cycle power plants	0.997	1.008	0.9906

Figure (2) shows the growth trend of the Malmquist-Leuenberger index throughout the study.



	88-89	89-90	90-91	91-92	92-3
Steam	1.021581057	0.991057262	1.015633333	0.977687975	0.996773
Gas	0.925736259	1.075504658	1.068621983	0.940214649	1.028132516
Combined-cycle	1.008888735	0.991615813	1.041480658	0.925792489	1.021826958

Figure 1. Trend of the Malmquist -Leuenberger Index

In general, the results show that gas power plants perform better than steam and combined cycle power plants in terms of green productivity growth, although the difference in the performance of the three types of power plants, according to the Malmquist-Leuenberger index is small. The mean values of the Malmquist-Luenberger index for gas, combined-cycle, and steam power plants are 1.007, 0.997, and 1.0005, respectively. Furthermore, the highest and lowest mean values of the Malmquist-Luenberger index were 1.06 and 0.982, respectively, for Shahid Mofateh (which is a steam power plant) and Konarak (which is a gas power plant), respectively. Therefore, the power generation method and type of power plant (i.e., gas, steam, and combined cycle power plants) have no significant impact on the environmental performance of power plants. The difference in the environmental performance of power plants, in turn, can be influenced by factors such as the type of fuel consumed, the life of the power plant, geographical location, and the level of technology rather than the method of production.

The type of fuel consumed by power plants is one of the most critical factors affecting the green productivity of power plants. Coal and natural gas are the most important fossil fuels for world power plants, and they account for 38.4% and 23.2% of the world's electricity production, respectively(IEA, 2018). While in Iran, coal's share of electricity production is negligible, natural gas accounts for about 85 percent of fossil fuels in power plants (https://amar.tavanir.org.ir/). The abundance of natural gas resources in Iran is an important advantage of the country in the field of thermal power generation. In the last recent decades, consumption of natural gas as a fuel for power plants has experienced significant growth. Natural gas has mostly replaced coal in many countries such as the US and UK. Coal-fired steam plants and Oil-fueled plants are converted and refitted to use natural gas to reduce environmental pollution and operating costs. According to the energy information administration (EIA,2016), the amount of CO2 emissions from electricity generation in the U.S. has dropped over the past two decades, while demand for electricity has remained relatively unchanged. The low price of natural gas, along with the higher efficiency of the combined cycle technology with natural gas, has made natural gas for power plants that have previously produced electricity from coal, an attractive choice. Meanwhile, electricity generation from coal has decreased in the U.S. for both economic and environmental reasons and increased pollution regulations.

Another point to note is that Iran is working on converting a significant proportion of its gas power plants to combined cycle power plants to increase the efficiency of its power plants[*]. Comparison of the results of the study on gas and combined cycle power plants also shows that combined cycle power plants are more efficient than gas power plants (The average of efficiency change index for gas plants and combined cycle plants is 1.005 and 1.008, respectively).

Conclusion

Increased power generation and significant thermal power share of total electricity generation resulted in increased greenhouse gas emissions. In this paper, using the Malmquist-Luenberger method, efficiency, and green productivity changes are measured for 31 thermal power plants (including 12 steam power plants, 13 gas power plants, and six combined cycle power plants) during 2009-2016.

The results of the study can be summarized as follows:

- The results show the increase in green productivity in gas power plants and the reduction in green productivity in combined cycle power plants. Also, green productivity in steam plants has not changed.

[*]. According to a strategic document of increasing the efficiency of the country's thermal power plants, the Ministry of Energy has planned to convert 72 gas plants to combined cycle power plants (12 units of 162 MW annually). (Tavanir, 2015)

- Since the difference in the average of the Malmquist-Luenberger index for tree types of power plant is negligible, and not all power plants of one type have the same performance (The highest mean value of the Malmquist-Luenberger is for a steam power plant (Shahid Mofateh), and the lowest mean value is for a gas power plant (Konarak)), it can be said that the power generation method has little effect on the environmental performance of the power plants. The green efficiency of power plants may be influenced by other factors, especially the type of fuel consumed by them. Therefore, it is suggested to study the effect of other factors on the green productivity of power plants.
- Among the factors affecting the environmental performance of power plants (i.e., gas power plants, steam power plants, and combined cycle power plants) , the type of fuel consumed by the power plant is essential. Although coal still accounts for 38% of fossil fuels consumed by power plants around the world and is at the forefront of fossil fuels in electricity generation but over the past two decades, many countries have replaced coal with natural gas to reduce greenhouse gas emissions. Therefore, given the country's abundant natural gas reserves, the increasing demand for electricity, and the increasing importance of environmental considerations, it is necessary to plan appropriately to increase the share of natural gas in electricity production and replace it with other fossil fuels in the electricity industry.
- The results of the study support the strategy of converting gas power plants to combined cycle power plants to increase efficiency.

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