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Influence of the fuel cell technology on CO2 emissions reduction in Iran according to outlook 2030

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Abstract: Iran is one of the major oil-producing countries in the world. However, because of the environmental pollutions of fossil fuels, pay attention to the development of the renewable energy sources must be considered. The principal objective of this paper is to assess the situation of the fuel cells' power capacity in Iran. CO2 is the most major greenhouse gas. According to the outcomes, at by 2030, the installed capacity of fuel cells is about 3451457 kWh, which can be reduced CO2 emissions if be applied instead of the fossil fuel power plants. According to the Paris Agreement, business as usual in Iran, CO2 emissions must be reduced by 4% (74 million tons) to 2030. The results show that on average, fuel cell technology can decrease CO2 emissions by replacing with one fossil power plant with the a value of 0.003% of 74 million tons. Based on the outcomes of the prediction, if the government of Iran pays attention to the development of the fuel cell technology, this technology has an acceptable potential in reducing CO2 emissions. Finally, to determine the external cost reduction using fuel cell technology and the amount of the income of the export saved natural gas, an economic analysis is performed.

keywords: fuel cell; CO2 emissions; 2030; Iran; environmental pollutions; renewable energy.

1. Introduction

Substituting renewable and clean sources with fossil fuel has been considered in recent years due to two major problems: environmental impacts and global warming (Jahangir et al., 2019; Mehrpooya et al., 2019). However, today fossil fuels have the most important role in supplying energy demand in the world(Mehrpooya et al., 2020). The biomass, wind, solar, hydropower, and geothermal are the most practical renewable resources (Mousavi et al., 2020). Hence, renewable energies can be a key role in solving these challenges and CO_2 emissions reduction (Roumi et al., 2017; Vivas et al., 2018; Yousefi et al., 2016). In the 21st century, hydrogen energy and types of fuel cells play an important role to reduce the emission of CO_2, climate change, and supplying permanent and secure energy for the future (Edwards et al., 2008). The main sources of hydrogen production routs can be categorized as natural gas (by steam reforming), biomass, coal, and water electrolysis(Edwards et al., 2008). Also, the Hydrogen energy has many applications such as storage of energy, the fuel of fuel cells for power generation, and transportation (Edwards et al., 2008; Yazdanfar et al., 2015). Also, renewable resources can be considered as a proper source of hydrogen, that solar energy has been reported as an economic recourse (Feeley III et al., 2008). Fuel cells are one of the most important applications of hydrogen energy. A fuel cell system

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consists of three main parts: cathode, electrolyte, and anode, that hydrogen and oxygen of the air enter the anode and cathode sides, respectively. DC electricity is considered as the main product of a fuel cell, which is produced by electrochemical reactions. Also, heat and water are the byproducts of a fuel cell (Haseli, 2018). Fuel cells have two important advantages: high efficiency and lack of destructive effects on the environment (McNutt and Johnson, 1999). The most common applications of fuel cells can be pointed to the power generating plants, transportation, remote village and electricity generators in building (Abdalla et al., 2018; Ahmed and Krumpelt, 2001). Based on the increasing energy demand in many countries, hydrogen and fuel cells will be as a sustainable energy resource and the final fuel for the man (Bahrami and Abbaszadeh, 2013). According to the 2030 protocol, the share of renewable energies should be exceeded 30% at no extra cost, in order to reduce CO_2 emission (Ghobadian et al., 2009; Said et al., 2018). Figure 1 exhibits the contribution of each energy sector to CO_2 emissions in Iran. Accordingly, many researchers have been studied on the plans of the countries about reduction of the CO_2 emissions at 2030 by using renewable energies. Namely, Zafar Said et al. (Said et al., 2018) proposed the plans of the government of the United Arab Emirates (UAE) for greenhouse gas reduction with a renewable energy mix in 2030. The results show that by increasing the share of the renewable energy mix by 5%, CO_2 emissions decrease 7%. Mohamed Azeroual et al. (AZEROUAL et al., 2018) predicted the power capacity of the solar and wind power plants in Morocco in 2030. The outcomes depict that the available capacity of the solar and wind energies at 2030, are about 4713 MW and 4087 MW, respectively. In Spain, the total required electricity must be supplied by renewable energies at 2030 (Girard et al., 2016). In (Girard et al., 2016), the outlooks of the renewable energies in Spain is studied, and the economic analysis is conducted. The results illustrate the PV solar energy is the most important source for electricity energy demand. Michelle Fisher (Fisher, 2016) introduced the key actions, which must be employed by government of the Scotland to 50% of the total energy demand is supplied by renewable energies in 2030. According to the International Energy Agency (IAEA), in 2011, Iran produced 520 million tons of carbon dioxide, which is among the top 10 countries in the world (Roumi et al., 2018; Yousefi et al., 2018b). In the top ten CO_2 emitters (TTCE), in 2030, the CO_2 emissions will increase 26.5 – 36.5% in contrast to 2005 (Dong et al., 2018). The performed investigations show that 68% of the global CO_2 emissions are produced by these 10 countries (Dudley, 2015). The Paris Agreement is a valuable convention which has been ratified in December 2015 (Dong et al., 2018). This agreement is about climate change, global warming and CO_2 emissions reduction, which has been marked by 160 counties (Ding and Li, 2017). These countries agreed that restrict global warming to 1.5°C, and an average temperature lower than 2°C. For achieving the target of CO_2 emissions reduction, the countries based on their national conditions, propose their Intended Nationally Determined Contribution (INDC). For instance, according to the INDC goal, Germany, Japan, South Korea, and Indonesia must be reduced the greenhouse gas emissions by 40%, 26%, 37% and 29%, respectively, in 2030 (Dong et al., 2018). Also, Iran, business as usual (BAU) must be reduced the CO_2 emissions by 4% in 2030. Figure 2 indicates actual and prediction of the contribution of energy resources for power generation until 2030 (Watanabe, 2007) . It is shown that, by 2030, the energy demand of the world is estimated about 34000 TWh. Natural gas and renewable energies have more growth than other energy resources and the best solutions for solving this problem.

In the present work, due to the CO_2 emissions concern in Iran, fuel cell technology is proposed as one of the promising solutions for this problem. Then, the power capacity of the fuel cells in Iran is forecasted in 2030. Moreover, the amount of reduced CO_2 emissions using fuel cell technology is investigated. Also, the types of fuel cells and Progress and the trend of development of the fuel cells are described. In addition, the main fuel cell projects in Iran are presented in detail. The power capacity of fuel cells in supplying energy for Iran in 2030 is estimated and the influence of the fuel cell technology on reducing CO_2 emissions is introduced. In the end, for calculating the number of income external cost reduction by fuel cell technology, an economic analysis is conducted. Figure 3 displays the target followed in this investigation.

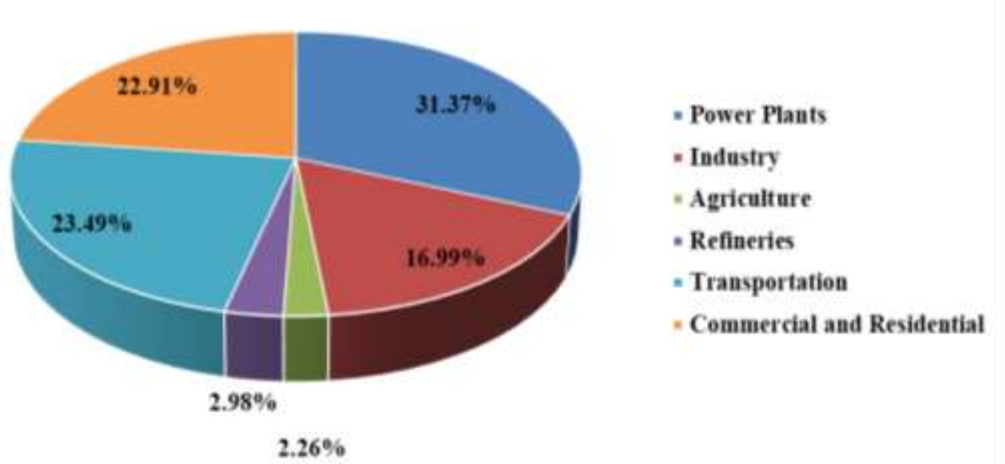

Figure 1. The share of each energy sector in producing CO_2 for Iran.

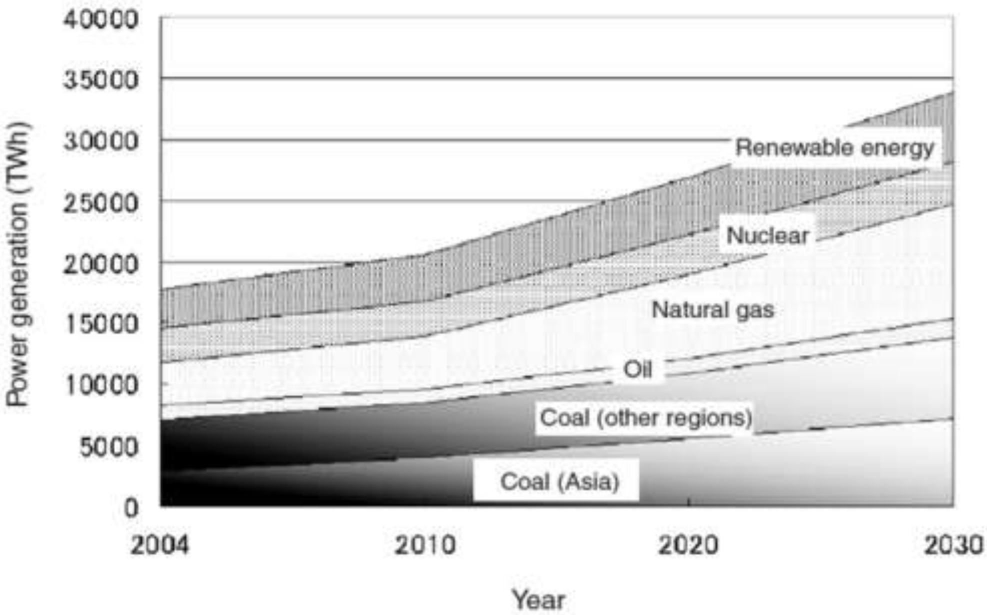

Figure 2. Prediction of the contribution of energy resources to power generation by 2030.

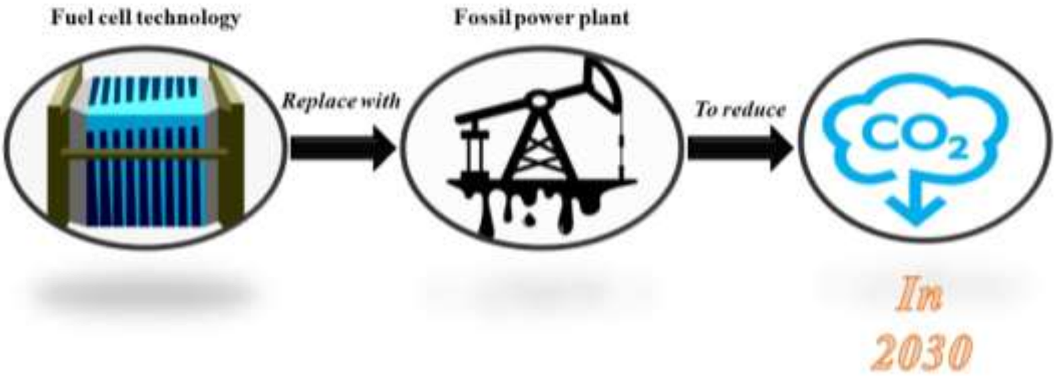

Figure 3. the objective followed in this study.

2. Materials and methods

2.1. Technology of the fuel cells

Fuel cells are converter devices, which convert the chemical energy of the fuel to the electricity directly, and named by kind of their electrolyte (solid or liquid) (Ghorbani et al., 2018). Electrochemical reactions are carried out on the catalysts of electrodes, which is between oxygen and hydrogen (Mehrpooya et al., 2016). Figure 4 denotes the schematic of a fuel cell system. The main kinds of fuel cells are the Proton exchange membrane (PEMFCs), Alkaline, Direct methanol, Phosphoric acid, Molten carbonate, and Solid oxide (Edwards et al., 2008), that the specifications of them with main advantages and disadvantages are summarized in Table 1. As can be seen, MCFC and SOFC are utilized in high operating temperatures. PEM and Alkaline fuel cells are suitable for low operating temperatures. The investigations on fuel cells have been started since the 19th century (1838) (Andújar and Segura, 2009), and so far, by developing the technology of fuel cells, applications of them, such as aircraft, buses, mobile, and portable computers have been expanded (Ball and Wietschel, 2009). Also, fuel cells have two main limitations: relatively high cost and a lesser extent the source of fuel (Abdalla et al., 2018).

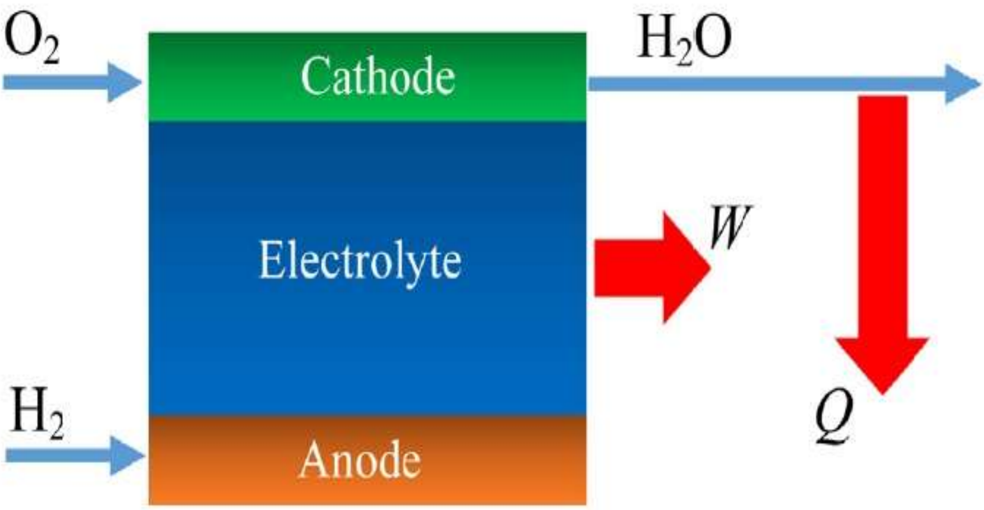

Figure 4. The schematic diagram of a fuel cell system.

Table 1. Summary of specifications of the fuel cell kinds

Kind of fuel cell	Conducted ion	Applications	Range of the operating temperature, pressure, and delivered voltage	Range of the output power (kW)	Advantages and disadvantages	Ref.
Direct methanol	H^+ (from the anode to the cathode)	Cameras/ notebooks/ mobile and vehicles.	60-120 °C 1 atm 1.1V	0.001 –100	Utilizing liquid fuel/without reforming process. Low efficiency/operating with high amounts of catalyst/ low long life.	(Andújar and Segura, 2009),(Dillon et al., 2004) and (Edwards et al., 2008)
Phosphoric acid	H^+ (from the anode to the cathode)	CHP/ water treatment plants/ building/ hospital and school.	150-200°C 1 atm 1.1 V	50–1000	Low volatility/ utilizing air directly. Using liquid electrolyte/ being heavy and big	(Andújar and Segura, 2009),(Yousefi et al., 2018a)
Proton exchange membrane	H^+ (from the anode to the cathode)	Automotive systems/ mobile/ building and portable equipment and vehicles.	60-80°C 1-2 atm 1.1V	0.01–250	High power density/ high voltage/ operating at low pressure/ being resistant of CO_2. Utilizing expensive catalyst and membrane/ low long life/ not resistant to CO and Sulphur	(Andújar and Segura, 2009),(Liu and Case, 2006) and (Edwards et al., 2008)
Molten carbonate	CO_3^{2-} (from the cathode to the anode)	fighting vehicles/ large power generation plants	550-650°C 1-10 atm 0.7-1 V	200–100,000	Generating a high amount of heat/ high efficiency/ Fast reactions. Using liquid electrolyte/ needing preheating before beginning work/ being the expensive cost of manufacturing	(Andújar and Segura, 2009),(Bischoff and Huppmann, 2002)
Solid oxide	O^{2-} (from the cathode to the anode)	auxiliary power unit (APU)/ CHP/ vehicles/ Medium- to large-scale power generation	500-100°C 1 atm 0.8-1 V	0.5–2000	Generating a high amount of heat/ Fast reactions/ high efficiency/ Using solid electrolyte. Not having an evolved technology/ not resistant to sulphur.	(Andújar and Segura, 2009), (Fuerte et al., 2007)
Alkaline	OH^- (from the cathode to the anode)	Mobile and spacecraft	70-130°C 1 atm 1.1-1.2 V	0.1–50	Operating at low temperature/ high efficiency/ being light and low volume. Low long life/ Using liquid electrolyte/ inlets of fuel cell, must be pure hydrogen and pure oxygen.	(Andújar and Segura, 2009), (Edwards et al., 2008)

2.2. The main projects of the fuel cells in Iran

In this section, some of the most important projects that have been carried out about types of fuel cells in recent years, are presented. The leading fuel cell technology countries are Japan, the United States, Canada, Germany, and Italy. Because Iran has a rich supply of crude oil, hydrogen that is the inlet fuel for fuel cells can be generated from crude oil (Ghobadian et al., 2009). Table 2 demonstrates the specification of the main projects that have been carried out about fuel cells in Iran. According to this table, in Iran, PEMFC and SOFC types of fuel cells have been utilized in the main projects that approximately have an acceptable output power.

Table 2. Specification of the occurred main projects that about fuel cells in Iran (Alipour and Sheykhan, 2017).

Name of the project	Fuel cell type	State	year	Power capacity (kW)
Design and manufacturing of (5 kW) PEMFC with the technology knowledge purpose	**Proton Exchange Membrane**	**Isfahan-Iran**	**2006**	**5**
Design and manufacturing of a 10-kW FC equipment with a possibility to generate both electricity and heat	**Proton Exchange Membrane**	**Taleghan-Iran**	**2012**	**10**
Design and manufacturing of a 100-W SOFC stack to seal technology development	**Solid Oxide**	**Tehran-Iran**	**2013**	**0.1**
Technology knowledge base of manufacturing a 50-W SOFC stack with the capability to use natural gas	**Solid Oxide**	**Tehran-Iran**	**2014**	**0.05**

2.3. Influence of the fuel cells on reduction of CO_2 emissions

Figure 5 depicts the prediction of the power capacity of the fuel cells in Iran to 2030 based on occurred projects from 2005 to 2015. Forecasting of fuel cells output power is performed by the FORECAST function of the Microsoft Excel Worksheet and Trend extrapolation. More information about this method has been reported in (Blackman Jr, 1971). The results show, at 2030, the power capacity is estimated with the value of 3451457 kWh. Also, according to this figure, gradient of the variations from 2007 (1105512 kWh) to 2012 (1193112 kWh) is slow. In Iran, for generating electricity, the amount of CO_2 emissions by Diesel, Combined Cycle, Gas and steam power plant are 747.264, 492.548, 876.245 and 817.226 gr/kWh, respectively (Bekhrad et al., 2018). So, in 2030, by utilizing fuel cells which do not produce any pollution instead of these power plants can be decreased CO_2 emission. Table 3 illustrates summarize of influence of the fuel cells on reduction of CO_2 emissions in Iran at 2030. According to this table, on average, fuel cell technology can decrease CO_2 emissions by 2531.02 ton. By 2030, the amount of CO_2 emissions for Iran based on the submitted Intended Nationally Determined Contribution (INDC) report to the Paris agreement as an official contract report in 19 Nov. 2015 using Business as Usual (BAU) system, is estimated to be about 1850 million tons. On the other hand, according to NDE of the Iran, the CO_2 emissions must be reduced by 4% (74 million tons). So, according to the obtained results, on average fuel cells technology can decrease 0.003% of 74 million tonnes CO_2 emissions by replacing with one fossil power plant.

Table 3. Summarize of influence of the fuel cells on the reduction of CO2 emissions in Iran in 2030 (Bekhrad et al., 2018)

Type of the power plant	CO_2 emissions (gr/kWh)	Reduced CO_2 emissions in one year (tons)	Contribution reduced percentage in 2030 (%)	Ref.
Diesel	747.26	2579.15	0.00348	(Bekhrad et al., 2018)
Combined Cycle	492.55	1700.00	0.00229	(Bekhrad et al., 2018)
Gas	876.25	3024.32	0.00408	(Bekhrad et al., 2018)
steam	817.23	2820.62	0.00381	(Bekhrad et al., 2018)

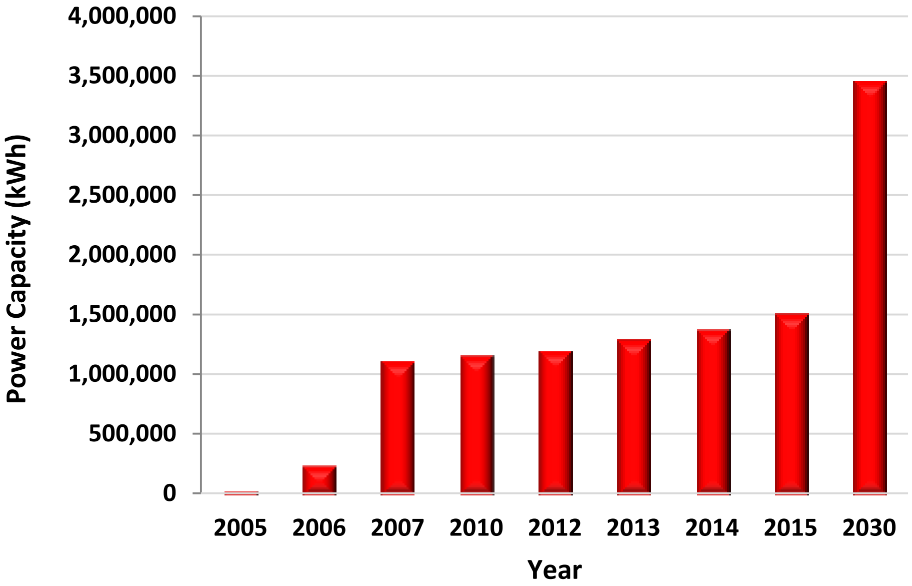

Figure 5. Prediction of the power capacity of the fuel cells in Iran to 2030.

2.4. Economic analysis

Reducing CO_2 emissions is profitable economically for each country. The cost of air pollutants and greenhouse gases emission to society is named external cost. In Iran, the external cost of the CO_2 emissions is about 26.25 \$/ton (Yousefi et al., 2018a). So, by utilizing fuel cells instead of fossil power plants, the external cost is reduced that is summarized in table 4. For instance, the external cost and amount of the reduced external cost by using fuel cell for the diesel power plant can be calculated as follows:

$$\text{External cost of the } CO_2 \text{ emissions by diesel power plant} = 26.25\,\frac{\$}{ton} \times 747.26\,\frac{g}{kWh} \times \frac{1\ ton}{1000\ g} = 19.62\,\frac{\$}{kWh}$$

$$26.25\,\frac{\$}{ton} \times 747.26\,\frac{g}{kWh} \times \frac{1\ ton}{1000\ g} = 19.62\,\frac{\$}{kWh}$$

$$\text{The reduced external cost by using fuel cell} = 19.62\,\frac{\$}{kWh} \times \frac{1}{747.26}\,\frac{kWh}{g} \times 2579.15\ ton \times \frac{1000\ g}{1\ ton} = 67702.69\,\$$$

For other fossil power plants, the calculations are similar to the above relations. According to table 4, in 2030, on average, the fuel cell technology by replacing with one fossil power plant, can decrease the 66439034$ external cost of the CO_2 emissions in one year. By replacing renewable energies such as fuel cells with gas power plants, the amount of the unused natural gas can be saved and exported to neighboring countries such as Turkey, that connected to Iran through pipelines. It is assumed that Price of each cubic meter of natural gas that exported to Turkey is 0.5 dollars in 2030 (Yousefi et al., 2018a). The emission index of the CO_2 and heat value of Iran's natural gas is 213.33 kg/10^6 kcal and 8600 kcal/m^3, respectively (Yousefi et al., 2018a). According to Table 3, the amount of the reduced CO_2 emissions by replacing fuel cell with one gas power plant in one year (2030) is 3024.32 ton. So, amount of the saved natural gas by utilizing Fuel cell technology instead of gas power plant, can be calculated as follows:

$$(213.33\frac{kg}{10^6\,kcal}\times 8600\,\frac{kcal}{m^3}\times\frac{1\,ton}{1000\,kg}\times\frac{1}{3024.32\,ton})^{-1} = 1648456\,m^3$$

So, the amount of income by exporting the natural gas to Turkey in one year (2030), is obtained as below:

$$1648456\,m^3\ \times 0.5\ \frac{\$}{m^3} = 824228\ \$$$

Table 4. Summarize of influence of the fuel cells on the reduction of external cost. of the CO_2 emissions in Iran in 2030.

Type of the power plant	External cost ($/kWh)	External cost reduction ($)
Diesel	19.62	67702.69
Combined Cycle	12.93	44625
Gas	23	79388.40
steam	21.45	74041.27

It can be seen, the income by exporting natural gas by using the fuel cell instead of one fossil fuel power plant is considerable. So, fuel cell technology can be considered as a suitable candidate for replacing fossil fuel power plants in Iran.

3. Conclusions

In this study, fuel cell technology is proposed as one of the effective solutions for CO_2 emissions concern in Iran. First, the technology of the fuel cells with detail is introduced. Then, by utilizing data on the power capacity of installed fuel cell power plants in Iran from 2005 to 2015, the power capacity is predicted about 3451457 kWh in 2030. In continue, the amounts of CO_2 emissions reduction by developing technology of the fuel cells in Iran in 2030 arebeing investigated and estimated. The results show that by using fuel cell technology instead of one fossil fuel power plant, on average, the CO_2 emissions decrease by 2531.02 ton in one year (2030). Finally, the economic analysis for computing the amount of incomes and external cost reduction by using fuel cell technology is implemented. The outcomes illustrate that by applying fuel cell technology, on average 66439034$ external cost is reduced in one year. Also, the amount of the saved natural gas in one year (2030) is obtained to be 1648456 m^3 and the income of the exportation to Turkey is about 824228 $. It was found, development and pay attention to the renewable energy resources such as fuel cells, can considerably help to the countries of the Paris Agreement, based on their INDC to decrease CO_2 emissions in 2030.

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