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Investigation into opportunities and challenges of cross-border electricity trade in Iran

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Abstract. Energy demand in Iran is increasing for many reasons including low price, large population, and Gross Domestic Product (GDP) growth. Its trend shows that this situation cannot continue for many years and thus, it needs reviewing in energy policy in Iran. The aim of this paper is to review the whole energy system of Iran and its possible future and to offer some policies on solving current and future problems. First of all, this study investigates the growing trend of some parameters like GDP, electricity price, population, CO_2 emission, and electricity consumption in eight years. After that, calculating the price of electricity generated in Iran under three different circumstances, this study can investigate the electricity and natural gas trade according to their prices. Studying the effects of renewable energy on CO_2 emission reduction, subsidy reduction, and water saving prompted this study to prepare and offer relevant policies. Ultimately, results reveal that energy saving in Iran is not held in high regard and two policies are offered accordingly.

1. Introduction

According to available statistics, in 2019, Iran was the owner of 9% and 16.1% of the world's total crude oil and natural gas reserves, being ranked fourth and second in the world in terms of reserves of oil and gas. Despite this potential, Iran's share in crude oil production and natural gas production is 3.7% and 6.12%, ranked seventh and third, respectively. Almost 5.7% of total natural gas produced and 2.05% of total crude oil produced were consumed in Iran [1]. In the electricity sector, in 2017, electricity production was 68.3 GW, while the practical capacity of power plants was 78.8 GW. Moreover, the total loss in the conversion, transmission, and distribution system was 12.3%, of which 2.9% of this loss is related to transmission and distribution [2]. In the same year, the total electricity consumption and CO_2 emission from power plants in Iran were reported to be about 255,026 GWh and 161.6 million tons, respectively [2].

According to available forecasts, if transmission and distribution loss remains constant, electricity consumption and CO_2 emission in Iran will arrive at 357,000 GWh and 4000 million tons, respectively, by

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20230, representing about 57% growth in electricity consumption [3]. Regarding this high growth in energy consumption in Iran, it is necessary to have an energy plan and make decisions for the future. Currently, Iran produces only 0.2% of its electricity from renewable resources, while Iran's geography and climate meet various forms of renewable energy technologies [1]. It is expected to move toward renewable energy and electricity trade to provide energy demand in the future and act on international CO_2 emission commitments. Iran's energy policies should be directed at increasing the security of supply and demand by supporting low-carbon industries.

In the past, electricity was not considered among tradable goods; however, recently, due to the geopolitical position of countries and their access to fossil fuels and energy security issues, the commercial sector looking for electricity is increasing [4]. The initiative of electricity trading generated by different renewable energy sources was introduced to Europe in the past several years by Greece and North Africa [5]. There are many studies on electricity trading, which was discussed from different aspects like economic, environmental, social, etc. Some of those studies will be discussed in this section. The move towards electricity trade is one of the solutions for responding to the growing demand for electricity. The electricity trade needs an integrated market and extension of the transmission network [6]. Most of the related papers have investigated the transmission network in terms of economy; however, to conduct a comprehensive evaluation, various assumptions should be considered. These assumptions can include inadequate financing, diverging interests, governance, and administration problems as well as political discourses and perceptions [6]. Chang and Li presented a dynamic linear programming model to find optimal transmission paths in Asian countries [7]. In 2016, Timilsina and Toman evaluated the benefits of South Asia's unlimited electricity trade quantitatively in the period of 2015 to 2040. They concluded that through unlimited electricity trade, the cost of electricity supply would decrease about $9 billion per year. Also, deployment of this policy in the region would reduce CO_2 emission by about 8% via replacing the coal-fired power plants in this period [8]. In another study, Parisio and Bosco claimed that the electricity trade would lead to homogenous prices in importing and exporting countries, which would have benefits for both [9]. Jacopo Torriti investigated effective factors in the electricity trade in 34 European countries. These factors included distance, price ratio, gate closer time, peak value, and aggregate demand as standard determinants. In this study, the main question was: Does privatization increase electricity trade? As demonstrated by the results, long-term privatization has many advantages, which can increase the electricity trade potential [10]. In 2017, Ahmed et al. evaluated the capacity of South Asian electricity trade. This investigation was carried out by considering consumption and production capacities and the potential of renewable energy production in each country. Finally, they presented the best path and program to trade electricity among these countries [11]. One of the main challenges in electricity trading is uncertainty and risk management. In order to address this challenge, in 2014, See et al. presented a method to investigate the electricity trade which included many scenarios regarding different uncertaineties [12]. In another research, Dagoumas et al. presented a dynamic model to manage the risks of the electricity trade according to the prediction of electricity price in neighboring countries and power-generation unit dispatch. The forecasting was done by Artificial Neural Network (ANN) approach and applied to the case studies of Greece and Italy [13].

One of the most important factors in Iran's electricity trade is electricity price since Iran is one of the countries that pays a high level of subsidy and the price of electricity is low in this country. Thus, it is necessary to know the real price of electricity generation and then, compared whether electricity trade is cost-effective or whether the low efficiency of Iran's power plant has caused gas trade to be more cost-effective. Another benefit of this study is providing an opportunity for comparing the generation price of renewable and non-renewable electricity.

Energy subsidy is an important issue of discussion for policy makers due to the costs it incurs to government and environmental externalities. The energy subsidy affects the energy demand, emission, and economy [14]. Energy subsidy in Iran causes high level of energy consumption, environmental problems, and inefficiency [15]. Knowing the amount of energy subsidy in the past and future can help policy-makers to enhance economic and environmental conditions. To this end, in this study, Iran's energy and water systems are reviewed. Also, the energy systems of Iran's neighboring countries are investigated. In order to evaluate electricity trade potential, the real price of electricity generation under different scenarios is calculated, and the electricity trade is compared with natural gas trade. This research study discusses not only the electricity subsidy paid by the government in the past, but also calculates the electricity subsidy in the future. Finally, the electricity system change by increasing the share of renewable energy is discussed.

2. Iran's electricity sector

In 2018, Iran was the world's 16th largest consumer of electricity [16] and due to high reliance on fossil fuels, the 11st largest emitter of CO_2 emissions [17]. Besides,

Table 1. Power plants in Iran.

Types of power plants	Power generation (MW)	Efficiency	CO_2 emission (Ton)
Steam	14891	37.6	$6.02 * 10^7$
Gas	20877	30.54	$5.7 * 10^7$
CHP	18828	46	$5.7 * 10^7$
Diesel	284	33.6	76461
Nuclear	1020	–	0
Hydro	11953	–	0
Solar	184	–	0
Wind	259	–	0
Biomass	24	–	0

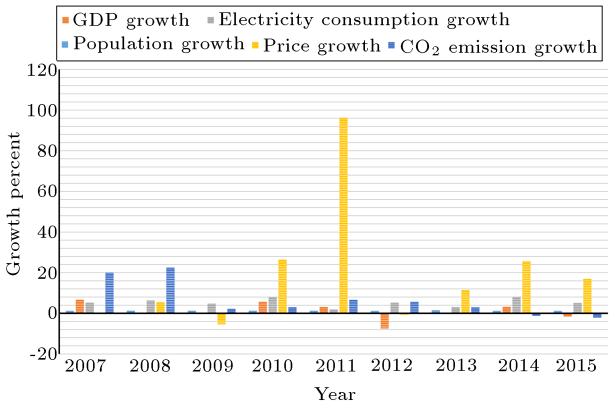

Figure 1. Electricity consumption and CO_2 emission growth in Iran in 2007–2015.

Iran is the second country in paying energy subsidies after China [18]. The country is a big electricity consumer on a per capita basis, with consumption equal to 1.71 times the world average and 0.78 times the Organisation for Economic Co-operation and Development (OECD) countries [3]. Electricity constituted merely 10.83% of final energy use in Iran in 2017. Iran is highly dependent on natural gas and oil-based fuel as a whole energy source [2]. Electricity prices in Iran are set by the government and vary by consumer group. The electricity tariffs in Iran rose in 2010 by around 96% [3] due to the new energy law. The main objective of this law was the reduction of subsidy. According to Figure 1, the least rate of growth in electricity consumption occurred in 2010. The event resulted from the fact that modifying electricity economy in Iran and changing the way of thinking about this field is the first step to modifying all industries.

Electricity consumption is related to population growth, economic growth, and the price of electricity. The most important issue that Iran should pay attention to is the need to conform to international environmental obligations. Therefore, Iran must make plans on higher electricity production and consumption.

Electricity production in Iran is dependent on fossil fuels and it causes greater emission. The information about power plants in Iran is reported in Table 1 and the capacities of power plants are shown in Figure 2. According to these figures, the gas turbine is the most common type of power plants and the share of renewable energy is near zero. In 2017, the electricity sector of Iran had a 30.53% share of CO_2 emission [2]. The trend of emissions from power plants in Iran is depicted in Figure 3 [3].

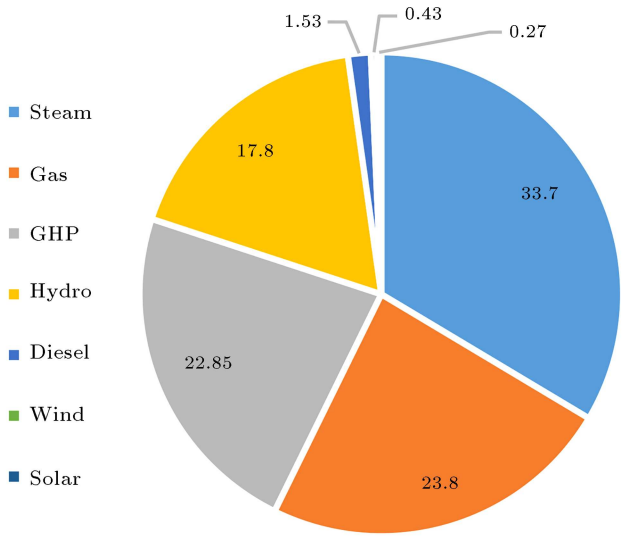

Figure 2. The share of different power plants in Iran.

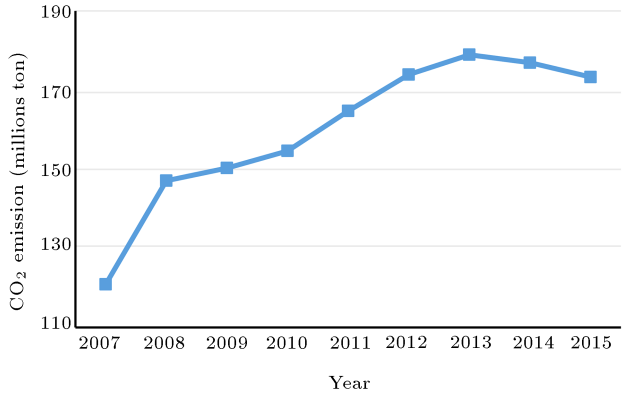

Figure 3. CO_2 emission from power plants.

3. Iran's water condition

The economic and population growth causes water scarcity around the world, and it is one of the most serious issues that affects human lives. In the next decades, water will be the most important resource in arid and semi-arid regions [19]. Iran is an arid and semi-arid country with an average precipitation less than the global average [19]. In Iran, the main resource for water is annual precipitation, which is around 413 billion m^3 [19]. As predicted by "International Water Management Institute (IWMI)", Iran is among the countries that will experience water crisis in 2025 [19]. On the other hand, Iran is located between the Caspian Sea in the north and the Oman and the Persian Gulf in the south. Thus, there are a considerable capacity of saltwater.

In 2015, water consumption by power plants was 453 million m^3 (this value is reported according to available statistics). Regarding water scarcity in Iran, water consumption in power plants should be managed better. Water consumption for cooling depends on the type of power plant. The choice of cooling system is the most important factor in water consumption. Estimates of water use for fossil fuels and nuclear power plants according to system cooling are reported in Table 2 [20,21].

On the other hand, water consumption in solar and wind power plants is negligible. Water consumption in photovoltaic and wind power plants is 0.021 (m^3/MWh) and 0 (m^3/MWh), respectively [20]. Around 20% of power plants in Iran uses wet cooling tower [22]. Water consumed in the steam power plants with dry cooling tower and wet cooling tower is about 0.19 (m^3/MWh) and 11.92 (m^3/MWh), respectively. Water consumed in CHP power plants is about 0.18 (m^3/MWh). Of note, these numbers are calculated based on available data reported for Iran power plants [3]. The number reported for water consumption in Iran has a big difference compared to international reports. Therefore, improving the water system in Iran's power plants is essential. Over the last decades, the price of water has never been considered as a parameter to calculate electricity price, and there was no movement to modify the way of consuming water by power plants in Iran as a consequence of this policy.

4. Power and natural gas export and import in Iran

Iran has power trade with Turkey, Armenia, Azerbaijan, Turkmenistan, Pakistan, Afghanistan, and Iraq. In 2015, Iran imported 4148.2 GWh power from neighboring countries and exported 9879.9 GWh. These statistics indicate that power export is more than two times the power import. Iran's electricity export and import statistics to neighboring countries is summarized in Table 3.

In order to enter the electricity trade, the actual generated electricity price should be considered. Moreover, losses in power plants and distribution system as well as efficiency of power plants are other important factors in electricity trade. In Iran, the price and trade of natural gas should be considered because much natural gas is used in power plants. Therefore, the mentioned factors should be compared to determine trade power or natural gas. Sometimes, Iran must import natural gas because of high consumption. Iran's natural gas import and export are summarized in Table 4.

The highest rates of the import and export of Iran's energy go to Turkmenistan and Turkey, respectively. Also, the electricity export to Iraq is significant. If Iran hopes to ensure energy security in the next decades, it should pursue more serious policies. Decision-making in energy trade depends on such indicators as emission in power plants, actual price of electricity generation in the country, price of electricity generation in neighboring countries, price of

Table 2. Water consumption by different power plants.

	Water consumption (m^3/MWh)	
Power plant's type	**Wet cooling tower**	**Dry cooling tower**
Gas turbine	0.7	0.19
Combined cycle	0.795	0.014
Steam	2.76	0.097
Nuclear	2.72	–

Table 3. Iran's electricity export and import in 2015 (MWh).

Country	Nakhichevan	Turkey	Armenia	Azerbaijan	Turkmenistan	Pakistan	Afghanistan	Iraq
Import	49965	–	1343724	3854	2750694	–	–	–
Export	49873	1722834	45025	–	475	456668	782497	6822497

Table 4. Iran's natural gas export and import in 2015 (million m^3).

Country	Turkmenistan	Azerbaijan	Turkey	Armenia	Nakhichevan
Export	–	–	7943.1	366.3	257.6
Import	8798.8	267.5	–	–	–

electricity import and export in Iran, price of natural gas generation, export and import natural gas in Iran, power plants efficiency, distribution and transformation costs, climate, water consumption in power plants, and regulations of export and import.

5. Energy system of neighboring countries

The investigation of neighboring countries energy system can introduce the opportunities and challenges of export and import. Electricity and natural gas information of Iran's neighbors is presented in Tables 5 and 6, respectively.

According to Tables 5 and 6, it becomes clear that Iraq, Turkey, and Afghanistan have enough potential for electricity export. New power plants in border provinces can be established to have electricity trade with these countries. Also, electricity import can be done with Turkmenistan, Pakistan, and Armenia.

In the case of natural gas, despite having massive natural gas reserves, Iran must import natural gas because of high consumption. The majority of natural gas is used in power plants. Nevertheless, it is possible to control natural gas consumption and trade through different policies. Making a decision about electricity or natural gas export is extremely dependent on electricity generation price. Thus, electricity generation price is calculated in the next section.

6. The price of electricity generation

In this section, the real price of electricity generation is calculated under three different scenarios to support policy makers for making suitable decisions. In this study, the following scenarios regarding the electricity generation price are considered:

1. Baseline scenario: In this scenario, the price of electricity generation is calculated based on subsidized fossil fuels;
2. FOB scenario: In the second scenario, the price of fossil fuels for electricity generation is considered as FOB price according to the law of target subsidies;
3. Export scenario: In this scenario, the price of electricity generation is calculated based on global fossil fuel prices.

Table 5. Power system in Iran neighbors.

Country	Power consumption (10^3 MWh)	Power generation (10^3 MWh)	Electricity import (GWh)	Electricity export (GWh)	Price \$/kWh
Turkey	229.20	261.8	7410	2960	0.095
Iraq	53.41	62.03	9802	0	0.00015
Turkmenistan	17.08	19.97	0	2885	0.013
Azerbaijan	21.66	20.29	1s00	462	0.041
Armenia	5.74	7.43	246	1360	0.096
Pakistan	92.23	94.65	452	0	0.025
Afghanistan	2.49	–	1572	0	0.071

Table 6. Iran and its neighbors' natural gas condition (million m^3).

Country	Natural gas consumption	Natural gas production	Import	Export
Turkey	81350	381	48430	624
Afghanistan	816	189	–	–
Azerbaijan	18200	29370	200	7320
Armenia	2730	–	0	0
Iraq	1270	1002	0	–
Iran	186000	184800	9550	8380
Pakistan	48060	39300	4125	0
Turkmenistan	67520	83700	0	40300

Table 7. Fuel and water consumed in all power plants.

Types of power plants	Natural gas consumption (10^6 m^3)	Gas oil consumption (10^6 Liters)	Fuel oil consumption (10^6 Liters)	Water consumption (10^3 m^3)
Steam	18965	90	4483	434840.5
Natural gas	22276	2959	–	0
CHP	20541	2804	–	18168.4
Diesel	–	13	–	–

Table 8. The number of labor in each section of power industry.

Sector	Number
Production	8867
Transformation	16724
Distribution	17201
Hydro power plants	1682
Total	44474

Table 9. CO_2 Emission from power plants in Iran.

Types of power plants	CO_2 emission (ton)
Steam	6.3×10^7
Natural gas	5.7×10^7
CHP	4.7×10^7
Diesel	55024

In this paper, the assumptions for calculation of actual electricity price are as follows: considering the cost of fuel consumed by power plants, the cost of water consumed, the cost of repair and maintenance of power plants, staff costs in the electrical industry, and social cost (These calculations are based on available information in 2016). The fuel and water consumed in all of the fossil fuel power plants in 2016 are reported in Table 7 [3].

In 2016, the number of people employed in the power industry in Iran, according to different areas, is reported in Table 8. If the average salary is assumed about 555.5 ($/person) on a monthly scale, total employee payments per year will be 29.6 millions $. In addition, the cost of repair and maintenance of power plants is 0.55 billion $ per year [2]. The external costs should be considered in energy and electricity policy, too. In Table 9, the amount of CO_2 emission is depicted in different types of power plants.

Table 11. Water and fuel cost in BAU.

Fuel	Price
Natural gas (IRR/m^3)	800
Fuel oil (litre/m^3)	1300
Gas oil (litre/m^3)	2100
Water (IRR/m^3)	5760

In the balance sheet of 2015, the price and quantity of pollutants are presented in Table 10.

The most important factor that affects electricity price is fuel price. Therefore, the electricity generation price is calculated in three different ways. The current situation of energy price is assumed as the first scenario. Currently, Iran is paying a large subsidy for electricity generation, and the deliverable fuel cost to power plants is negligible. Therefore, in the first scenario, the fuel cost reported in Table 11 [3] was considered for calculation. Accordingly, the price of electricity generation will be around 0.02 ($/kWh).

For the second scenario, the law of target subsidies has been considered. According to this law, the fuel price for domestic consumption should be based on the oil products price (FOB Persian Gulf) and export price. This law also includes power plants. In this scenario, the price of gas oil and fuel oil consumed by the power plants should be increased to 90% of the Persian Gulf FOB price and the price of natural gas should be increased to 75% of the export price. The fuel price for electricity generation, in this scenario, is summarized in Table 12. According to prices in this table, the price of electricity generation is 0.12 ($/kWh).

In the final scenario, the calculation of the electricity generation price was done according to the global prices summarized in Table 13. Accordingly, the global price of electricity in Iran is 0.17 ($/kWh).

Table 10. External cost of emissions.

Average emission and price of emission	CO_2	NO_X	SO_2	Spm
Average emission (gr/kWh)	660.65	2.383	1.661	0.115
Price ($/gr)	1.56733E-05	0.00189845	0.00470199	0.0027594
Total price$/kWh	0.010354558	0.00452402	0.00781	0.0003173

Table 12. Water and fuel cost in law.

Fuel	Persian gulf FOB price	Export price
Natural gas	–	15 $\frac{\text{US cent}}{\text{m}^3}$
Fuel oil	20.52 $\frac{\text{US cent}}{\text{liter}}$	–
Gas oil	31.5 $\frac{\text{US cent}}{\text{litre}}$	–
Water	10000 $\frac{\text{IRR}}{\text{m}^3}$	–

Table 13. The global price of fuels.

Fuel	Natural gas ($\frac{\text{USD}}{\text{m}^3}$)	Gas oil ($\frac{\text{USD}}{\text{liter}}$)	Fuel oil ($\frac{\text{USD}}{\text{liter}}$)	Water ($\frac{\text{USD}}{\text{m}^3}$)
Price	0.175	0.875	0.5912	0.128

7. Energy subsidy in Iran

Iran is a huge energy subsidizer and energy price has a notable impact on energy efficiency. Energy intensity of Iran increased by 53% between 1990–2015 [15]. This large number can be controlled by reducing energy subsidy. As illustrated in Figure 1, as a result of energy price increase in 2010, the growth of energy consumption decreased considerably to achieve energy consumption reduction.

In this section, the electricity subsidy in the years 2008 to 2030 is calculated with the assumption that fuel prices will remain the same; electricity consumption will grow 50% by 2030 [23]; and the electricity price increases 10% annually. According to the global price of oil and natural gas and efficiency of power plants in Iran, the subsidy that is paid by the government for electricity generation is depicted in Figure 4. These numbers are without water subsidy, although water is important, too.

In 2008, oil price was 94 ($/barrels) and it decreased in 2009; consequently, the subsidy was reduced, too. Next, both oil price and subsidy increased; however, the oil price decreased again in 2015. In the same year, the electricity subsidy was at its lowest value and the subsidy was almost 6 billion $ which was the highest throughout the world [24]. If the oil price remains constant till 2030, the electricity subsidy for

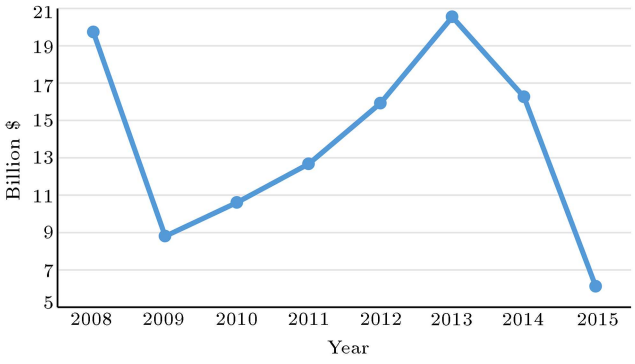

Figure 4. The subsidy paid by the government between 2008–2015.

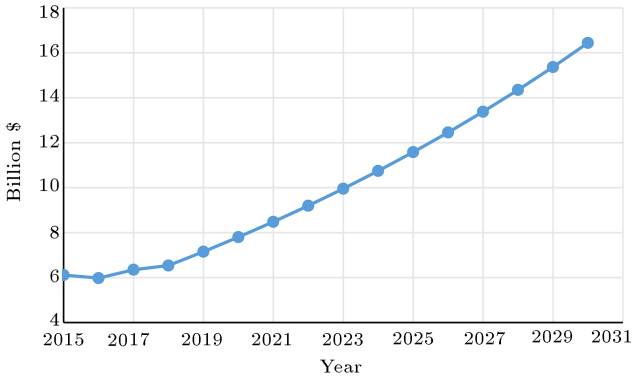

Figure 5. The subsidy to be paid in the next decades.

Iran is given in Figure 5. If the oil price increases, the subsidy will rise surely.

8. Policy recommendation

The results of this paper illustrated that policy-makers of the energy sector in Iran should consider economic aspects. In this section, two policies considering the economic aspects of energy sector are offered. Iran is a middle-income country, but highly dependent on the oil and natural gas trade. Thus, it is vital to know the pros and cons of energy trade. In 2015, the export and import of natural gas for Iran were 9.1 and 8.6 billion m^3, respectively. These values show that Iran must import natural gas in the winter sometimes. On the other hand, the electricity export is more than two times the electricity import in Iran.

With regard to the efficiency of power plants (37%), the electricity produced per cubic meter of natural gas is about 3.7 kWh. Therefore, Iran consumed 2.7 billion m^3 versus 9879.9 GWh of electricity, which is exported. If Iran seeks to export electricity, its price should be from 0.12 ($/kWh) to 0.17 ($/kWh); otherwise, it will not be profitable. Another important key that Iran should notice is CO_2 emission from power plants. Iran should try to control it and considering this issue, it is not rational to produce electricity with fossil fuels and export it due to around 6.5 million tons

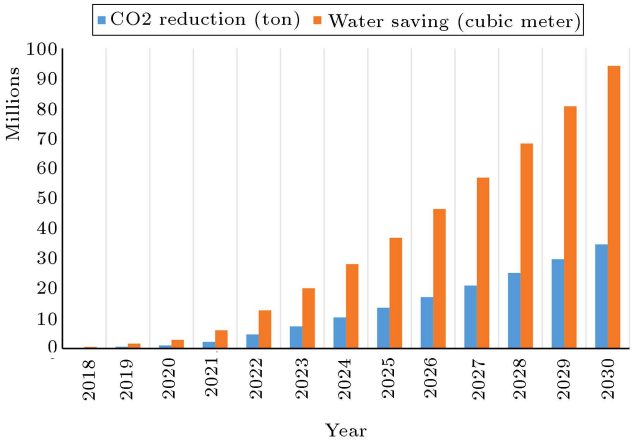

Figure 6. The CO_2 reduction and water saving by renewable energy.

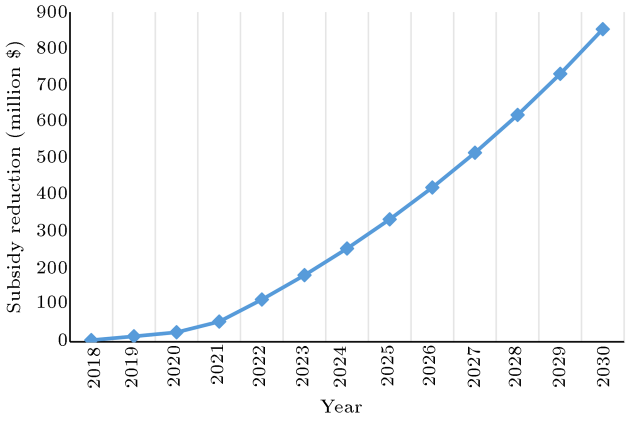

Figure 7. The trend of subsidy reduction.

of CO_2 emitted versus electricity export in 2015. If Iran exports natural gas instead of electricity, it will be more affordable and environmentally-friendly.

Based on Iran's Development Perspective Program until 2025, the country must increase the share of renewable energy to 5% of its electricity production capacity. Thus, in 2025, renewable electricity should increase by 22856.16 GWh. In that case, it will be quite useful for Iran. Not only does it cause fuel saving, but it also facilitates CO_2 reduction and water saving. The prices of solar electricity and wind electricity are reported as follows: photovoltaic price was almost between 0.36–0.1 (\$/kWh) and the wind price was 0.1–0.05 (\$/kWh) from 2010–2017 [25]. The price of electricity generation in Iran under the two scenarios described in the last sections is more than renewable electricity generation price. It seems that the price of renewable electricity is affordable in Iran. If Iran's plan for renewable energy development (increasing the share of renewable energy to 5% until 2025 and 10% by 2030) is materialized, it will indeed be rewarding, hence subsidy reduction by 4.2 billion \$, reduction of CO_2 emissions by 168 million tons, and 455.6 million m^3 water saving. These trends are shown in Figures 6 and 7.

9. Conclusion

Iran's economy is heavily dependent on the oil and natural gas trade. Currently, Iran exports electricity. The subsidy that the government pays for electricity generation is high, and electricity generation is done through fossil fuels. Thus, the electricity sector incurs high costs due to th CO_2 emission, water consumption, and consumption of fossil fuels, which make electricity export unjustified. Iran should not continue the electricity export now; however, if it tries renewable electricity, electricity export will be generally acceptable. Otherwise, the natural gas and oil export will be more affordable options. Iran has good renewable energy potential, and its price is the same with, or cheaper than, the real price of electricity generation by fossil fuels. Therefore, it is best for the country to invest in renewable energy for the greater benefit of CO_2 emission reduction. Since solar and wind energy generation does not require water, water saving becomes more convenient and the subsidy on electricity generation is reduced. For the government to achieve economic development, subsidy reduction in different sectors is among the priorities for investment.

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