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TREND OF ENERGY PRODUCTION AND CONSUMPTION IN IRAN BY PREDICTING THE STATE OF RENEWABLE ENERGY IN THE HORIZON OF 2040

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Abstract

Energy consumption in Iran has high rate due to its geographical location as well as high industrial and residential energy consumption. Drought and the impossibility of using some hydroelectric power plants, global warming and extravagant electricity consumption, as well as novel technologies (e.g., cryptocurrency mining) are the reasons to cause the increment of electricity consumption. The main reason for national power outages is the instability of energy production and consumption balance. Such events disturb the balance between the production and consumption of electricity. The utilization of renewable energies is one of the primary solutions to eliminate the gap between energy production and consumption. Taking into consideration the current conditions and the 20-year forecast of energy consumption and production in Iran, a vast gap can be observed between these two cases. In this paper, by considering two different scenarios using renewable energy, this gap is addressed, causing the amount of power production to exceed the amount of consumption in the long term.

Keywords: Renewable energy, Sustainability, Energy policy, Energy production, Energy consumption

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1. INTRODUCTION

Nowadays, energy has found a crucial place in the socio-economic evolution in countries. Hence, optimizing energy consumption and management has been recognized as a critical method to guarantee energy supply which is examined by energy policymakers [1, 2]. Having 9% of oil resources and 16.1% of gas resources, Iran is ranked 4th and 2nd in the world, which shows the richness of the country in terms of fossil resources [3]. However, due to immethodical energy consumption, Iran is the leader in the world in terms of energy intensity index [4]. Furthermore, the amount of released environmental pollution is remarkable. In Iran, carbon dioxide emissions via fuel consumption rose from 6.8 tons per capita in 2008 to 7.01 tons per capita in 2018 [5]. In order to enhance energy efficiency in Iran, various regulations and policies have been implemented, such as consumption pattern management along with the roles of the Sixth Development Plan. Despite the efforts, none of these measures have successfully curbed the uncontrolled rise in energy utilization [6]. Consequently, improving energy performance has now become imperative in Iran. Some of the articles in the policy field are cited below:

Souhankar et al. [7] performed an informative structural model to classify future energy policies in Iran. Their procedure was designed according to energy balance relations, validated and assessed through 47 expert panels regarding 9 main themes. According to the results, the recommended priority policies were explained based on increasing electricity distribution and transmission performance, optimizing the standard of the appliances and processes, and online monitoring of networks. In the residential sector, efforts have been made globally to optimize household energy consumption [8]. However, Mahar et al. [9] discovered that energy efficiency policies in Pakistan were not effectively implemented owing to a lack of institutional units. Also, similar challenges exist in Iran. Krati [10] evaluated the potential of energy performance in the building sector of Arab countries and studied ongoing regulations and policies. The results showed significant variation in energy consumption among Arab nations, with the potential for substantial energy reduction through strict energy efficiency codes. Barkhordar et al. [11] examined the effect of energy subsidy reform on energy efficiency in industries, identifying challenges related to low investment in optimizing energy efficiency. Mohammadi et al. [12] studied another aspect of energy efficiency in Iran. It has been shown that there is a potential to decrease gas emissions in petrochemical complexes by 2.53 million tons per year and decrease natural gas consumption by 1100 million cubic meters per year. Furthermore, several researches have been performed on increasing energy efficiency and making appropriate policies in different sectors of Iran's industries [13-16].

One of the most suitable solutions for sustainable energy supply based on preserving the environment is using renewable energies such as solar, wind, geothermal,

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biomass, etc. [17-20]. According to the 2018 BP Energy Outlook, renewable energy is projected to experience significant growth, increasing five times by 2040 and accounting for approximately 14% of worldwide initial energy [21]. In a review paper by Afsharzadeh et al. [22], the importance of renewable energy at rural and national levels, its connection to sustainable rural development, and the challenges faced in promoting renewable energy technologies were discussed. The authors concluded that while renewable energy had the potential for development in rural areas, it could encounter obstacles related to management, infrastructure, social, and economic factors. Fadai et al. [23] examined the potential of renewable energies in Iran and the ongoing state of industries, focusing on achieving objectives and targets outlined in the fourth national development plan. The researchers also addressed the barriers and reasons for the non-attainment of these targets. Zahedi et al. [24] performed a strategic investigation of renewable energy policy, sustainability, and optimizations in Iran. According to the results, Iran has a vast potential in renewable energies. Among renewable energies in Iran, wind energy has a priority over other sources in terms of marketing and economics.

Hence, this paper aims to assess the potential of energy conversion in several sectors, explain the role of renewable energy in providing part of the country's energy, and propose suitable scenarios that take into account Iran's energy market circumstances.

2. ENERGY CONSUMPTION AND PRODUCTION IN IRAN

The nominal and actual energy production and consumption from 2011 to 2020 have been extracted from Iran's energy balance report in Table 1 and Figure 1. Accordingly, the unfavorable energy state is confirmed by measuring the average nominal efficiency of power plants in the peak demand mode, which can be reduced by 75%. Also, more than 20 gigawatts of gaps are observed between the nominal and actual energy production at the peak time in recent years. Also, according to Iran's energy balance report, the amount of actual power production has been lower than energy consumption since 2015, and this difference has been increasing by now. The existing recommended solution is to increase energy production through the renewable portfolio.

3. PREDICTION OF THE NOMINAL PRODUCTION, PRODUCTION IN THE PEAK DEMAND MODE, AND CONSUMPTION OF ENERGY IN THE HORIZON OF 2040

3.1. Prediction of the nominal power production the in the horizon of 2040

In Table 2 and Figure 2, the trend of nominal energy production based on linear, logarithmic, and polynomial estimates are calculated until 2040. Logarithmic and linear estimations have provided more reasonable solutions than the polynomial approximation

TABLE 1. NOMINAL AND ACTUAL POWER PRODUCTION, POWER CONSUMPTION, AND POWER PRODUCTION IN THE PEAK DEMAND MODE BETWEEN 2011 AND 2020.

Year	Nominal power production (GW)	Actual power production (GW)	Power consumption (GW)	Power production in the peak demand mode (GW)
2011	65.217	57.42	53.18	48.91
2012	68.9	60.6	55.98	51.67
2013	70.2	61.8	57.52	52.65
2014	73.2	63.9	62.21	54.9
2015	74.2	64.7	65.41	55.65
2016	76.5	66.6	67.7	57.37
2017	78.8	68.2	72.3	59.1
2018	80.47	69.76	73.01	60.35
2019	83.48	72.4	76.41	62.61
2020	85.31	74.13	-	63.98

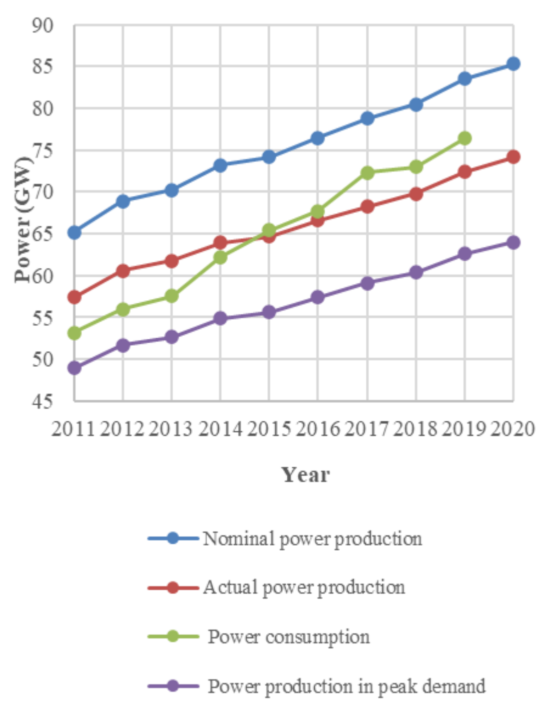

Fig. 1. THE TREND IN NOMINAL AND ACTUAL POWER PRODUCTION, POWER CONSUMPTION, AND POWER PRODUCTION IN THE PEAK DEMAND MODE BETWEEN 2011 AND 2020

TABLE 2. PREDICTION OF THE NOMINAL POWER PRODUCTION IN THE HORIZON OF 2040

Year	Linear prediction (GW)	Logarithmic prediction (GW)	Polynomial prediction (GW)
2021	87.48	87.61	88.61
2022	89.62	89.74	92.12
2023	91.76	91.87	96.22
2024	93.90	94.01	101.01
2025	96.04	96.13	106.56
2026	98.18	98.25	112.98
2027	100.33	100.38	120.37
2028	102.47	102.5	128.81
2029	104.61	104.62	138.37
2030	106.75	106.74	149.18
2031	108.89	108.86	161.32
2032	111.03	110.98	174.88
2033	113.18	113.1	189.95
2034	115.32	115.21	206.63
2035	117.46	117.32	225.01
2036	119.60	119.43	245.17
2037	121.74	121.54	267.22
2038	123.88	123.65	291.24
2039	126.03	125.76	317.32
2040	128.17	127.86	345.57

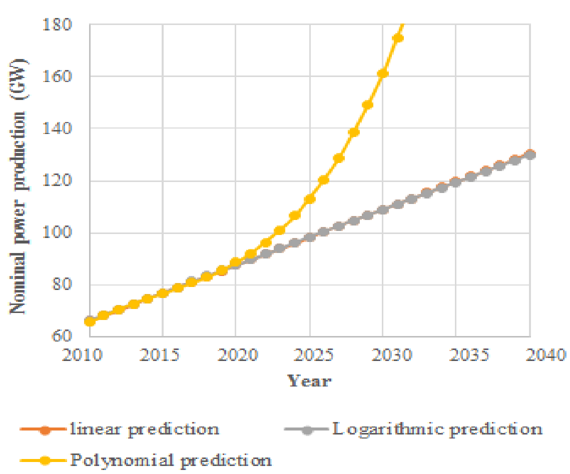

Fig. 2. PREDICTION TREND OF THE NOMINAL POWER PRODUCTION IN THE HORIZON OF 2040

Equations 1 to 3 present relations for estimating the amount of nominal energy production for linear, logarithmic, and polynomial prediction, respectively.

$$2.1417x - 2910.9,\ R - squared = 0.9938 \tag{1}$$

$$2986.6\, lnx - 21548,\ R - squared = 0.9939 \tag{2}$$

$$0.01539x^3 - 64.4177x^2 + 89840.5055x - 41766323.90000,\ R - squared = 0.9957 \tag{3}$$

3.2. Prediction of the actual power production the in the horizon of 2040

Similar to the previous case, for forecasting the actual power of the system, three approximations (i.e., linear, logarithmic, and polynomial) are used, the results of which are shown in Table 3 and Figure 3.

TABLE 3. PREDICTION OF THE ACTUAL POWER PRODUCTION IN THE HORIZON OF 2040

Year	Linear prediction (GW)	Logarithmic prediction (GW)	Polynomial prediction (GW)
2021	75.6	75.09	77.42
2022	77.34	76.83	81.12
2023	79.08	78.56	85.61
2024	80.82	80.29	91.01
2025	82.57	82.02	97.42
2026	84.31	83.75	104.99
2027	86.05	85.48	113.82
2028	87.80	87.21	124.04
2029	89.54	88.94	135.75
2030	91.28	90.66	149.09
2031	93.03	92.39	164.17
2032	94.77	94.11	181.11
2033	96.51	95.83	200.01
2034	98.25	97.55	221.02
2035	100.01	99.27	244.24
2036	101.74	100.99	269.79
2037	103.48	102.71	297.81
2038	105.23	104.43	328.38
2039	106.97	106.14	361.65
2040	108.71	107.85	397.72

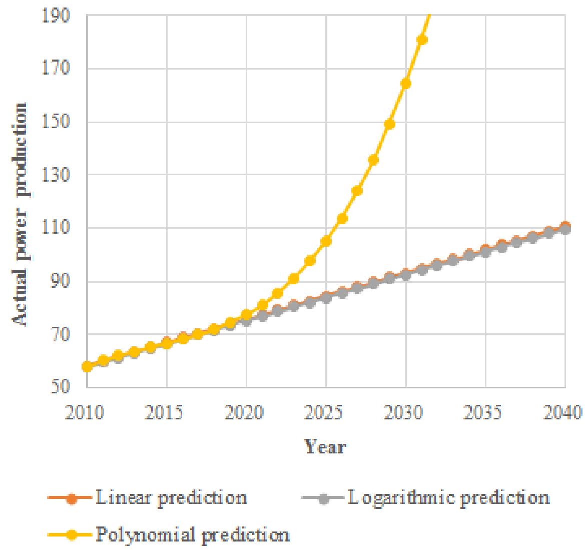

Fig. 3. PREDICTION TREND OF THE ACTUAL POWER PRODUCTION IN THE HORIZON OF 2040

For predicting the amount of actual energy production in linear, logarithmic, and polynomial modes, equations 4 to 6 are expressed below:

$$1.743x - 2364.6,\ R - squared = 0.9911 \quad (4)$$

$$2430.5\, lnx - 17532,\ R - squared = 0.9911 \quad (5)$$

$$0.01979x^3 - 82.8163x^2 + 115477.0398x - 53673362.2742,\ R - squared = 0.996 \quad (6)$$

3.3. Prediction of the power consumption in the horizon of 2040

Based on the revealed data, the same trend is expected for energy consumption in the future. By surveying the 10-year trend of energy consumption, using the three approximations, the trend of energy consumption is predicted until 1420. The prediction is demonstrated in Table 4 and Figure 4.

TABLE 4. PREDICTION OF THE POWER CONSUMPTION IN THE HORIZON OF 2040

Year	Linear prediction (GW)	Logarithmic prediction (GW)	Polynomial prediction (GW)
2021	82.72	82.43	77.7
2022	85.70	85.41	76.91
2023	88.68	88.37	74.81
2024	91.67	91.34	71.21
2025	94.65	94.3	65.95
2026	97.64	97.26	58.85
2027	100.62	100.22	49.72
2028	103.61	103.18	38.38
2029	106.59	106.14	24.66
2030	109.57	109.09	8.37
2031	112.56	112.04	-10.65
2032	115.54	114.99	-32.6
2033	118.53	117.94	-57.66
2034	121.51	120.88	-85.99
2035	124.51	123.83	-117.8
2036	127.48	126.77	-153.24
2037	130.46	129.71	-192.5
2038	133.45	132.64	-235.76
2039	136.43	135.58	-283.2
2040	139.42	138.51	-335.01

Equations 6 to 9 are written for estimating the amount of power consumption for linear, logarithmic, and polynomial prediction, respectively.

$$2.984x - 4095.3,\ R - squared = 0.9901 \quad (7)$$

$$4160.2\, lnx - 30055,\ R - squared = 0.9903 \quad (8)$$

$$-0.02991x^3 + 125.0822x^2 - 174325.4347x - 80983511.867081,\ R - squared = 0.9928 \quad (9)$$

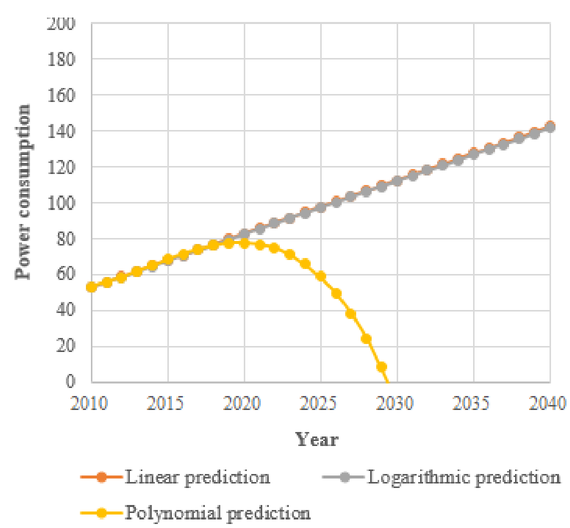

Fig. 4. PREDICTION TREND OF THE ACTUAL POWER PRODUCTION IN THE HORIZON OF 2040

4. RESULTS

4.1. The energy production and consumption gap considering the renewable energy impact

According to Table 5, with the current trend of increasing the capacity of power plants in Iran, the gap between energy production and energy consumption will continue to rise in the upcoming years. So, constructing renewable power plants is a potential solution to fill this gap.

TABLE 5. THE GAP BETWEEN ENERGY PRODUCTION AND CONSUMPTION IN THE HORIZON OF 2040

Year	The gap between production and consumption in the actual mode (GW)	The gap between production and consumption in the peak demand mode (GW)
2011	+4.24	-4.27
2012	+4.62	-4.31
2013	+4.28	-4.87
2014	+1.69	-7.31
2015	-0.71	-9.76
2016	-1.1	-10.33
2017	-4.1	-13.2
2018	-3.25	-12.66
2019	-4.01	-13.8
2020	-5.6	-15.75
2021	-7.12	-17.11
2022	-8.36	-18.49
2023	-9.6	-19.86
2024	-10.84	-21.25
2025	-12.08	-22.62
2026	-13.33	-24
2027	-14.57	-25.38
2028	-15.81	-26.76
2029	-17.05	-28.13
2030	-18.29	-29.51
2031	-19.53	-30.89
2032	-20.77	-32.27
2033	-22.02	-33.65
2034	-23.26	-35.02
2035	-24.49	-36.41
2036	-25.74	-37.78
2037	-26.98	-39.15
2038	-28.22	-40.54
2039	-29.46	-41.91
2040	-30.71	-43.3

4.2. Two possible energy production and consumption scenarios in the horizon of 2040

a) First scenario:

The first scenario of the Ministry of Energy is to produce 10,000 megawatts (10 gigawatts) of renewable electricity by 2026. If this trend continues, it will lead to an average increase of 2.5 GW of renewable power production per year. The average increase of 2.5 GW of renewable electricity causes the gap between energy consumption and actual production power to disappear from 2027 onwards. From that year onwards, the superiority of production will be observed over the consumption. Finally, in 2040, 50 GW of renewable electricity will enter the country's energy network, causing the actual production power to exceed the consumption amount (i.e., 19.29 GW). If these calculations are considered for the peak mode, the gap between power consumption and actual power production will be filled in 2036. In 2040, the amount of power production will overtake the power consumption in the peak mode by 6.7 GW. These estimations are valid if the trend of increasing power production and other non-renewable sources continue with the current trend. If thermal electricity production is accelerated, this gap will be compensated earlier.

This scenario, in case of integration with a further increase in the capacity of the country's power plants, will fill the gap between energy production and consumption faster, and the surplus of energy production will also be used for export. The electricity exported in 2019 was 343.8206 gigawatt-hours, equivalent to 2.28 gigawatts (more than 80% of which was exported to Iraq). Now, by increasing the share of renewable energy, the surplus between power production and consumption can be exported, and the country can benefit from the economic point of view.

b) Second scenario:

The second scenario is the annual production of 5 GW of renewable electricity, according to which there has been no gap between the actual power production and power consumption by 2023. Furthermore, in 2040, the amount of the produced power will be 69.29 GW more than the power consumption. Also, the operation of this scenario will cause the amount of power production to exceed the amount of consumption in the peak demand state from 2026 onwards. By continuing this trend until 2040, the power production will increase by 56.7 GW more than the power consumption in the peak demand state. The operation of this scenario calls for governmental efforts and high investment cost. Because the trend of increasing the production of the country's power plants has been around 1 to 3 gigawatts in recent years, the assumption of increasing 5 gigawatts via renewable–based systems seems a bit improbable.

5. CONCLUSION

Energy consumption in Iran has high rate due to its geographical location as well as high industrial and residential energy consumption. Due to the country's energy economy, which is mainly based on fossil fuels, attention to renewable power plants has been neglected. Considering the low growth of energy production from non-fossil sources, there is a gap between energy production and consumption, especially during the peak demand mode. One of the most effective solutions to overcome this instability is using renewable energy capacity, which the government's policies seek to increase the country's energy production from this source.

In this paper, considering two different scenarios, the effect of renewable energy in filling the gap between power production and consumption was investigated. According to the results, if the first scenario is used, which is the production of 10 gigawatts of renewable electricity until 2024 and maintaining the production trend in the upcoming years, the gap between power production and consumption in the actual mode will disappear in 2027. In 2036, the gap between production and consumption will also be resolved in the peak demand mode. In the second scenario, which is ambitious, with an annual increase of 5 gigawatts of renewable electricity, the gap between power production and consumption, in the actual mode and peak demand mode, will disappear in 2023 and 2026, respectively.

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