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Renewable Energy Transition in Iran: A Path Towards Sustainability and Energy Security

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ABSTRACT

The increasing energy consumption in Iran and other countries has caused numerous problems. These problems include environmental issues, energy imbalance, threats to energy security, unemployment, dependency on other countries, and more. This article examines the necessity of developing renewable energy in Iran, focusing on its environmental, economic, and social benefits. The increasing energy consumption and reliance on fossil fuels have led to numerous challenges, including environmental pollution, energy imbalances, and economic vulnerabilities. Renewable energy sources, such as solar and wind energy, offer sustainable and efficient solutions to address these issues. With its diverse natural resources and favorable geographical conditions, Iran possesses significant potential for the development of renewable energy. This study analyzes the status of renewable energy-related legislation in Iran, the global trends in the utilization and development of these resources, and their role in enhancing energy security and creating employment opportunities. Furthermore, a comparative assessment of water consumption and greenhouse gas emissions between fossil fuel-based and renewable energy power plants highlights the environmental advantages of renewable energy sources. The findings reveal that adopting renewable energy not only improves environmental quality but also contributes to job creation and the reduction of energy poverty. By leveraging its solar and wind potential and implementing appropriate supportive policies, Iran can position itself as a regional leader in renewable energy development and contribute to global efforts to combat climate change.

1. Introduction

Iran, a nation with a legacy of ancient civilization and a strategic position in the Middle East, finds itself at a pivotal moment concerning its energy future. The country's energy sector is currently dominated by fossil fuels, primarily oil and natural gas, which are extensively used for both domestic consumption and a significant portion of its export revenue (Azadi et al., 2017). This high dependence, however, presents a complex array of challenges, including economic vulnerabilities, environmental degradation, and geopolitical risks. These issues are not unique to Iran but are increasingly recognized as global concerns that necessitate a shift towards sustainable energy solutions to combat the adverse effects of climate change and achieve long-term energy security (Albu, 2021).

The environmental repercussions of Iran's persistent reliance on fossil fuels are well-documented and deeply concerning. The combustion of these fuels releases substantial quantities of greenhouse gases, including carbon dioxide, methane, and nitrous oxide, which are the primary drivers of global warming and subsequent climate change (Hasanzadeh et al., 2023). Iran is already witnessing the effects of these changes, with studies indicating a notable increase in average temperatures, a rise in the frequency and intensity of droughts, and disruptions in established rainfall patterns, which have profound implications for agriculture and water resource management (Asadi Nik et al., 2023; Kazemi Garajeh et al., 2024). These changes not only threaten food security and access to clean water but also increase the incidence of extreme weather events like dust storms and heat waves, thereby posing severe risks to public health and exacerbating economic vulnerabilities (Harper et al., 2022). Therefore, transitioning towards renewable energy sources is essential to mitigate these environmental impacts and align with global efforts to reduce greenhouse gas emissions and combat climate change.

Economically, Iran's dependence on fossil fuels also creates inherent vulnerabilities. The global market for fossil fuels is notoriously volatile, with price fluctuations often dictated by geopolitical factors, supply chain disruptions, and international market dynamics (Kurtz, 2012). This

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instability can significantly impact Iran's national budget, which is heavily reliant on revenues from oil and gas exports, thus making the economy susceptible to external shocks. Furthermore, the eventual depletion of these finite resources poses a long-term threat to the country's economic stability (Vaclav, 2016). Iran Oil Consumption was reported at 1,816.840 Barrel/Day th in Dec 2023. In 2023, Iran relied on fossil fuels for 94% of its electricity generation. Its per capita emissions were above the global average. Renewable energy, on the other hand, presents a more stable and secure energy supply option. Renewable sources, such as solar, wind, and geothermal, are domestically available and are less prone to international market price volatility (IRENA, 2022). Hydro is Iran's largest source of clean electricity at 4%. However, the share of wind and solar in total electricity generation is only 0.6%. The global average for wind and solar share is at 13% and its neighbour Türkiye at (16%) (Shokri, 2024). The adoption of renewable energy technologies can also spur innovation, create new employment opportunities in manufacturing, installation, and maintenance sectors, and enhance energy independence by reducing the need for fossil fuel imports. Therefore, embracing renewable energy is a strategic economic decision that can bolster the country's financial stability and promote sustainable economic development. The transition to cleaner energy sources creates new job opportunities, strengthens energy security, and reduces economic vulnerabilities associated with fossil fuel market fluctuations (World Bank, 2023). In addition, the adoption of renewable energy can reduce energy poverty in deprived areas and give millions of people access to electricity for the first time. In this case, to overcome obstacles, governments, private institutions, and international organizations should cooperate to create support frameworks, invest in research and development, and encourage public awareness and participation (IEA, 2022). For example, countries such as Germany and China have demonstrated the effectiveness of strong policies and subsidies in accelerating the adoption of renewable energy, which can serve as models for other countries.

In addition to environmental and economic considerations, the pursuit of renewable energy also has significant geopolitical implications for Iran. The world is increasingly moving towards renewable energy, and nations that lag behind in this transition risk being left behind technologically and economically (REN21, 2022). By investing in renewable energy, Iran can position itself as a forward-thinking nation capable of meeting its energy needs sustainably, reducing dependence on volatile international oil markets, and enhancing its self-reliance in the energy sector. In this way, renewable energy can contribute to greater stability and security within the country and the region as a whole. Due to its special geographical features, Iran has a huge potential for the development of renewable energy. The country has vast desert areas with high solar radiation, which makes solar energy a promising option. In addition, the mountainous regions and plains of Iran provide suitable conditions for wind energy projects (IRENA, 2023). Solar energy is one of the prominent sectors in Iran's renewable energy sector. Iran has an average of about 280 sunny days and is expected to have a great potential for solar energy production in the forecast period. By exploiting its natural advantages and implementing forward-looking policies, Iran can overcome its challenges and establish itself as a regional leader in renewable energy development. Such a transition would not only respond to immediate domestic problems such as air pollution and water scarcity but also contribute to global efforts to combat climate change. Despite these advantages, renewable energy forms only a small part of the country's energy mix. Recent studies emphasize the critical need for a coordinated and context-sensitive approach to energy transfer. By adopting renewable energy, communities can tackle environmental challenges, and boost economic development. In fact, moving towards renewable energy is not only an option, but it is a necessity for the well-being of future generations.

This study analyzes the status of renewable energy-related legislation in Iran, the global trends in the utilization and development of these resources, and their role in enhancing energy security and creating employment opportunities. Furthermore, a comparative assessment of water consumption and greenhouse gas emissions between fossil fuel-based and renewable energy power plants highlights the environmental advantages of renewable energy sources.

2. Renewable Energy in Iranian Laws

In Iranian laws, the topic of renewable energy has been addressed. A review of the laws from the past two decades shows that at least 10 legal articles have mentioned renewable energy, as indicated in Table 1.

3. Environmental Benefits of Using Renewable Energy

Using renewable energy sources has numerous benefits, many of which are directly related to the environment. Each renewable energy source has its own unique benefits and drawbacks. The best choice for a particular location will depend on a variety of factors, such as climate, available resources, environmental concerns, and financial considerations. Table 2 briefly compares the types of renewable energy.

In this article, to clarify the benefits of using renewable energy, the comparison of greenhouse gas emissions and the amount of water required in fossil and renewable power plants is addressed. Mousavi Reine and Yousefi 2020, examined the water consumption of various thermal power plants in Iran and compared these amounts with solar and wind power generation systems in an article. Their research results indicate that the water consumption for steam power plants with a wet cooling tower system is 2.2 liters per kilowatt-hour, 1.5 liters per kilowatt-hour for steam and combined cycle power plants with a once-through cooling system, 0.2 liters per kilowatt-hour for steam and combined cycle power plants with a dry cooling system, 0.025 liters per kilowatt-hour for gas power plants, and 0.07 liters per kilowatt-hour for photovoltaic power plants.

Table 1. List of Iranian legal laws

Year	Subject	Law Name
2001	Setting the guaranteed purchase rate of electricity from renewable energy sources	Law on adjusting part of the government's financial regulations
2009	Development of electricity production from renewable sources as one of the uses of funds obtained from the implementation of the targeted subsidies law	Targeted subsidies law
2010	Mandating long-term guaranteed purchase contracts from renewable sources from the value of saved fuel	Energy consumption pattern reform law
2015	Providing part of the necessary resources for the production of renewable and clean electricity from electricity tariffs	Law on supporting the electricity industry
2015	Financing renewable energy projects from fuel consumption savings	Law on removing barriers to competitive production and improving the financial system of the country
2017	Setting a goal to increase the share of renewable and clean power plants to at least 5 percent of the country's electricity capacity by the end of the plan	Sixth development plan law
2017	Providing at least 30% of the annual increase in the country's electricity capacity from renewable energy	Clean air law
2022	Construction of 1000 mw renewable power plants by industries / financing for guaranteed purchase of renewable electricity from fuel savings certificates	Law on removing barriers to the development of the electricity industry
2022	Industries with a consumption power greater than one megawatt are required to supply one percent of their annual electricity needs through the construction of renewable power plants. This amount should reach at least five percent by the end of the fifth year of the law. Otherwise, the ministry of energy is obligated to calculate the mentioned percentage of the electricity consumption of these industries at the renewable electricity tariff and collect it from the industries.	Law on the leap in knowledge-based production
2024	Setting a quantitative target for the production of 21,000 million kilowatt-hours of renewable electricity by the end of the plan	Seventh development plan law

Table 2. Comparison of types of renewable energy

Feature	Solar	Wind	Hydropower	Geothermal	Biomass
Availability	Widely	Variable	Site-Specific	Site-Specific	Widespread
Reliability	Intermittent	Intermittent	Reliable	Reliable	Variable
Emissions	Low	Low	Low	Low	High
Land use	Moderate-high	Moderate	High	Low	High
Cost	Decreasing	Decreasing	High	High	Low-Moderate
Enviromental impact	Low	Low-moderate	High	Low-moderate	Moderate-high

Table 3. Water Consumption in various power plants in the country.

Power plant type	Power plant name	Cooling system	Power generation (mwh)	Water consumption (l/kwh)
Steam	Shahid Montazeri	Dry	11000000	0.15
	Toos	Dry	3967364	0.15
	Ramin	Wet	10500000	2.33
	Iranshahr	Dry	1423000	0.15
	Shahid Rajaee	Dry	6400000	0.15
	Bistoon	Wet	4029739	2.06
Gas	Sabalan	-	2500000	0.025
	Kashan	-	1300000	0.025
	Ferdowsi	-	2510000	0.025
	Ofogh Mahshahr	-	2000000	0.25
	Chabahar	-	1400000	0.25
	Samangan	-	3250000	0.02
Combined cycle	Zavareh	Wet	2966957	1.3
	Neyshabur	Dry	6025714	0.2
	Abadan	Dry	5800000	0.2
	Shahid Rajaee	Dry	5800000	0.2
	Shoubad	Dry	3400000	0.2
	Pareh Sar	Once-Through	1626878	1.5
Wind	Manjil	-	78698	0
Photovoltaic	Persian Gulf	-	12547	0.08

Their study results on 20 power plants in the country, including 6 steam power plants, 6 gas power plants, 6 combined cycle power plants, and wind and solar power plants, are shown in Table 3.

They continued to calculate the average water consumption in the process of each power plant. Their study results, as shown in Table 4, indicate that the water consumption of renewable power plants is significantly lower than that of fossil fuel power plants (Mousavi Reine & Yousefi, 2020).

The next topic in the environmental impacts section relates to the emission of carbon dioxide gas per kilowatt-hour of electricity produced. IPCC studies indicate that coal-fired power generation has the highest emissions, while wind power plants have the lowest emissions. In Fig. 1, the carbon dioxide emissions of different energy sources are compared.

The amount of greenhouse gas emissions in Iran is high. For this reason, Iran is the eighth largest producer of greenhouse gases in the world, after Japan. In Fig. 2, the ranking of countries is displayed (Quaschning, 1998).

The studies show that countries with a high share of carbon dioxide emissions are more inclined to use renewable energy production. Iran ranks 134th in the world in this ranking. The share of countries in renewable energy production is shown in Fig. 3 (UNEP, 2023).

4. Energy Imbalance

One of the challenges facing our country is energy imbalance. Energy imbalance means that the supply of energy in the country is less than the demand. Studies indicate that energy consumption in the country's power plants is increasing. However, in 2023, the peak electricity demand was around 73,663 megawatts, while the maximum supply was 61,220 megawatts. As a result, the country faced an energy imbalance of about 12,000 megawatts in 2023 (UNEP, 2023). Every year, the demand for electricity increases significantly, and if investments are not made, the imbalances will continue to grow. Additionally, the annual

Table 4. Average water consumption in the process of each power plant.

Power plant type	Cooling system type	Water consumption (l/kwh)
Steam	Dry	0.15
	Wet cooling tower	2.19
Gas	-	0.025
Combined cycle	Dry	0.175
	Wet cooling tower	1.33
	Once-through	1.53
Wind	-	0.0
Photovoltaic	-	0.075

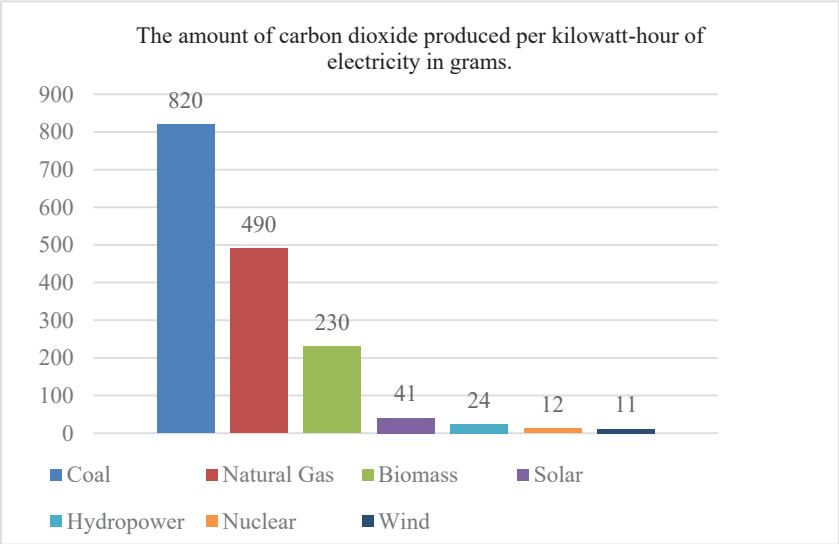

Fig. 1. Carbon dioxide emissions in different energy sources

gas imbalance in the country is around 120 million cubic meters per day, with a maximum imbalance of 315 million cubic meters per day during the cold season. In 2023, the maximum imbalance for gasoline and diesel exceeded 15 million liters per day. To meet domestic demand, imports and purchases of related products from domestic units amounted to four billion dollars) Energy & Efficiency, 2008). In Fig. 4, the energy consumption in the country's power plants is specified.

5. Energy Security

Energy security varies from country to country. Energy security in oil and gas importing countries means the security of energy supply, However, energy security in oil and gas exporting countries means the security of demand. According to the International Energy Agency, energy security is equivalent to sufficient access, affordability, and reliability of fuels and energy services. It includes the availability of resources, reducing dependency on imports, minimizing environmental pressures, efficient markets, reliance on local clean resources, and affordable and fairly distributed energy services. Many studies have been conducted on energy security and energy security risks worldwide. Studies show that the consumption of non-renewable energy sources increases energy security risk. Additionally, the use of renewable energy sources in the energy mix of countries helps improve their energy security (Sütterlin & Siegrist, 2017).

6. Energy Security

Another advantage of using renewable energy is the job creation associated with it. According to the International Renewable Energy Agency (IRENA), in 2020, around 12 million jobs were created in the renewable energy sector worldwide.

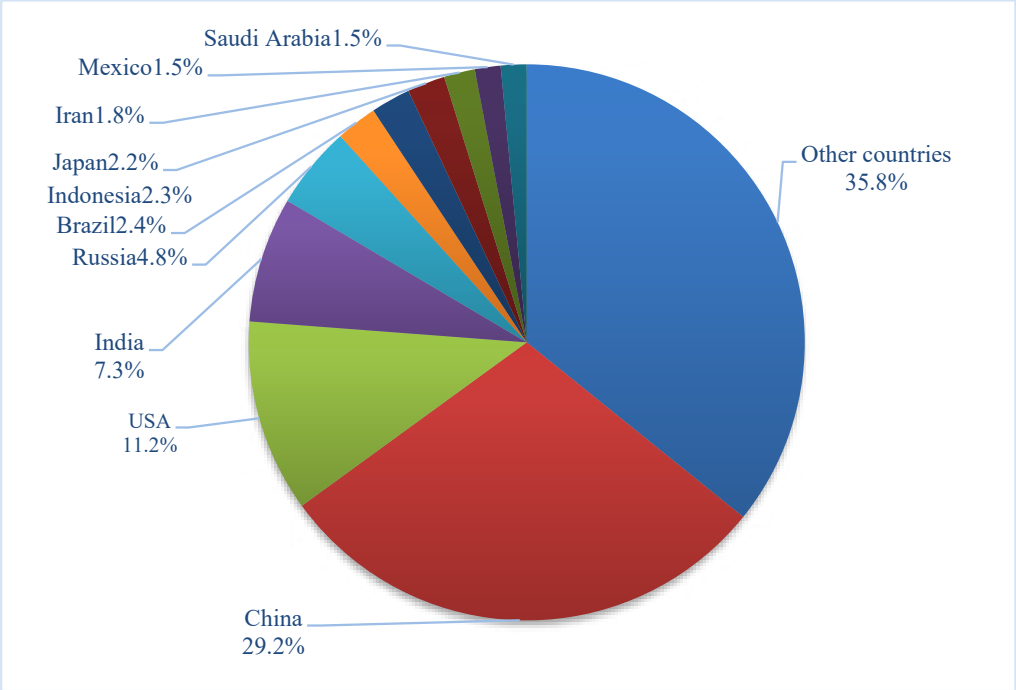

Fig. 2. Greenhouse gas emissions in different countries

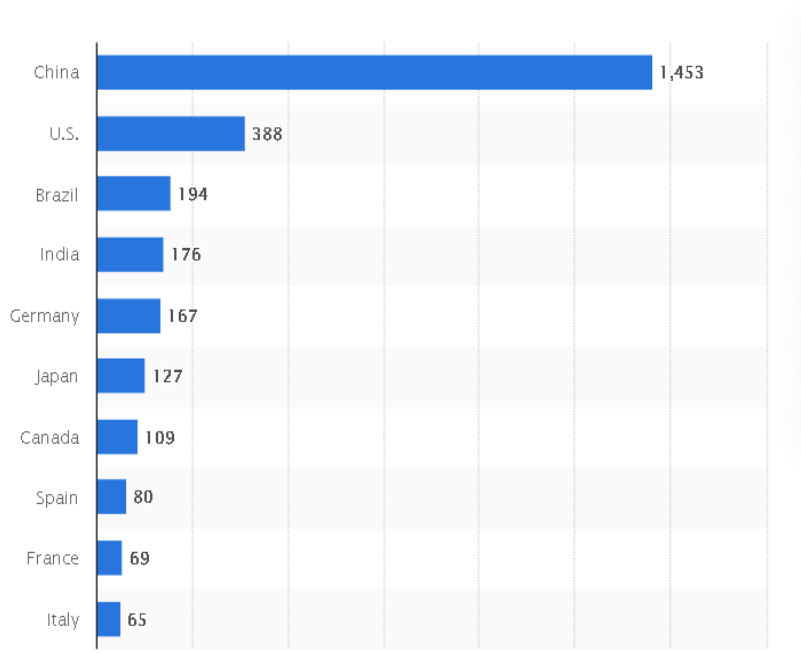

Fig. 3. Renewable energy production capacity in different countries in 2023 (in Gigawatts)

China alone accounted for 39% of these jobs, with solar energy leading the way with 4 million jobs. 32% of the jobs created have gone to women. In Fig. 5, the jobs created in various renewable energy technologies from 2012 to 2020 are shown.

Regarding the above chart, bioenergy refers to liquid biofuels, solid biomass, and biogas. In the hydropower sector, direct jobs are meant, while in other energy sectors, it includes geothermal energy, concentrated solar power, heat pumps, municipal and industrial waste, and ocean energy.

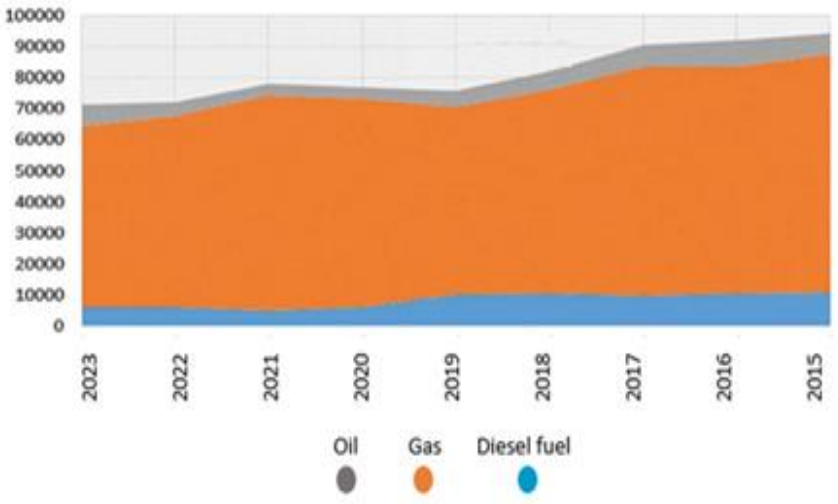

Fig. 4. Fuel consumption of power plants in the country

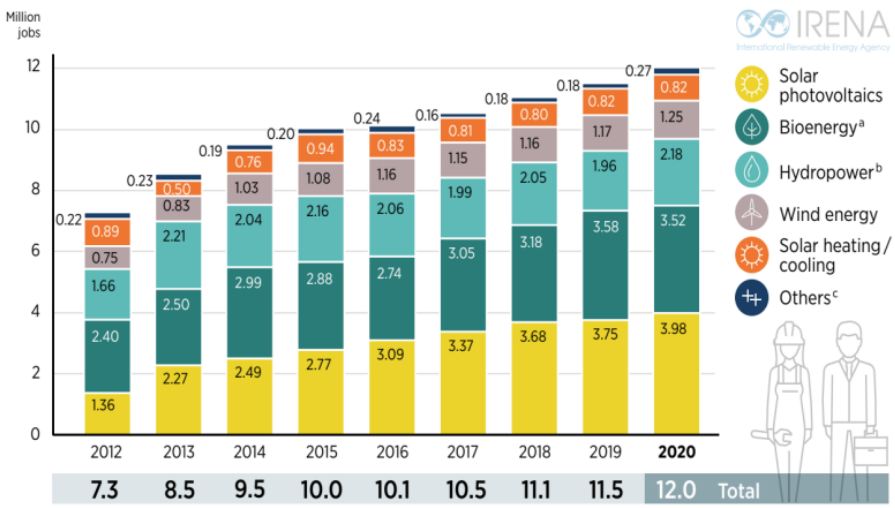

Fig. 5. Number of jobs created in renewable energy from 2012 to 2020

7. Costs of Building Renewable Energy Power Plants

There are various Fig.s regarding the construction of renewable energy power plants worldwide. However, in all these calculations, one common point is the reduction in price due to increased supply. However, it is still more expensive than non-renewable energy power plants. In Table 5, the estimated prices and the prices for the years 2025 and 2015 for two solar and wind power plants are shown (Boisgibault & Kabbani, 2020).

8. Ranking of Renewable Energy Sources by Popularity

By studying the above content, it can be understood that due to environmental, economic, and employment effects, there should be a ranking for the construction of renewable energy power plants in the world. In 2024, Energy Digital Magazine ranked renewable energy sources based on their popularity. Based on these studies, the ranking of renewable energy sources is shown in Fig. 6. As can be seen in Fig. 6, solar energy is the most popular, while hydrogen fuel cells are the least popular (World Bank, 2023).

Table 5. Costs of renewable power plant construction

Percentage change	Investment cost (in dollars per kilowatt-hour)		Power plant type
	2025	2015	
57% reduction	790	1810	Solar panels
15% reduction	3950	4650	Onshore wind
12% reduction	1370	1560	Offshore wind

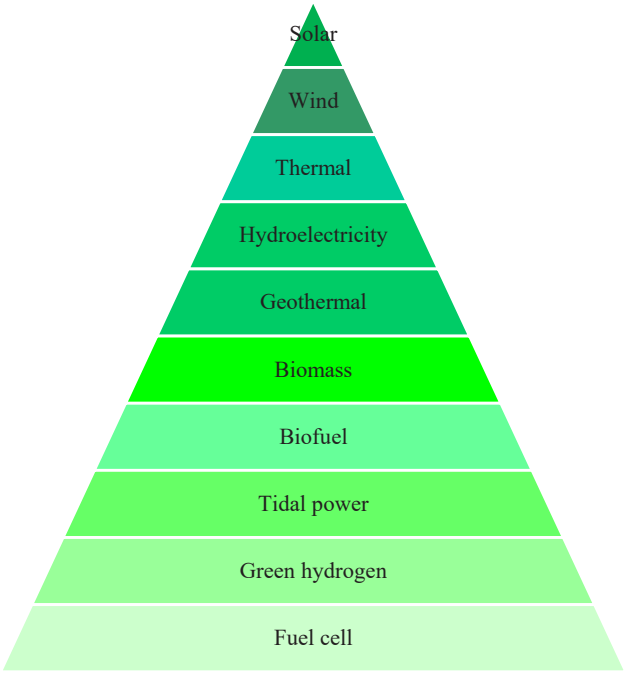

Fig. 6. The ranking of renewable energy sources

9. Potential of Renewable Energy in Iran

Studies by the Renewable Energy and Energy Efficiency Organization (SATBA) show that Iran, with a score of 4.99, ranks highest in the region for solar energy potential, after Oman, Saudi Arabia, and the UAE. Additionally, Iran, with a wind speed of 8.41 meters per second and a wind density of 744, has the best wind energy potential after Afghanistan. However, despite having the highest potential for biomass energy after Armenia, Azerbaijan, and Turkey, the potential for biomass energy production in Iran is low (IEA, 2022).

The world is experiencing a growing interest in renewable energy, and many countries are setting ambitious targets to reduce their dependence on fossil fuels. Iran, while still heavily reliant on fossil fuels, also recognizes the potential of its renewable resources and is making efforts to diversify its energy mix. Table 6 describes the renewable energies available in Iran and global usage.

Table 6. Renewable energies available in Iran and global usage

Category	Global Usage	Iran Usage	Potential in Iran
Solar	Moderate	Limited	Good
Wind	Rapidly growing	Minimal	Limited
Hydro	Growing	Limited	Moderate
Geothermal	Moderate	Growing	Good
Biomass (Biofuel)	Moderate	Research Stage	Moderate

10. Conclusions

Iran, given its increasing energy consumption and the challenges arising from dependency on fossil fuels, urgently needs to transition toward renewable energy sources. This research highlights that the development of renewable energy resources, such as solar and wind power, can significantly mitigate environmental, economic, and social challenges. By reducing greenhouse gas emissions, consuming less water, and lowering pollution levels, renewable energy offers an effective solution for improving environmental quality. The economic benefits of these resources include creating new job opportunities and reducing reliance on fossil fuel imports. Additionally, the adoption of clean energy enhances the country's energy security and decreases vulnerability to global market fluctuations. Due to its geographical advantages, Iran holds substantial potential for developing solar and wind energy. Through investments in infrastructure and the implementation of supportive policies, the country can position itself as a regional leader in renewable energy development. An analysis of domestic legislation reveals that significant legal measures have been enacted to support the development of renewable energy; however, coordinated and comprehensive implementation remains essential. Countries like Germany and China have demonstrated that strong supportive policies and investments in innovative technologies can accelerate the adoption of these energy sources. Ultimately, transitioning to renewable energy not only resolves environmental and economic issues but also plays a critical role in combating global climate change and facilitating sustainable development. This shift is an imperative step to ensure the welfare of future generations and the preservation of natural resources.

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