**International Journal of Power Electronics and Drive System (IJPEDS)**
Vol. 16, No. 3, September 2025, pp. 2082~2089
ISSN: 2088-8694, DOI: 10.11591/ijpeds.v16.i3.pp2082-2089 

# The Jordanian passage to sustainable electrical power: case study of challenges and opportunities

**Emad Awada**
Department of Electrical Engineering, Faculty of Engineering Technology, Al-Balqa Applied University, Amman, Jordan

**Article Info**

***Article history:***

Received Sep 19, 2024
Revised May 28, 2025
Accepted Jul 23, 2025

***Keywords:***

Electrical energy policy
Electrical energy security
Jordan electrical challenges
Renewable electrical energy
Sustainable electricity

**ABSTRACT**

As the global energy sector faces significant challenges due to limited conventional resources and environmental concerns, many countries have adopted precautionary measures to secure and develop new energy resources. For instance, Jordan faces a severe shortage of natural conventional energy resources, compounded by rapid population growth driven by both locals and refugees. With over 90% of its energy imported, Jordan heavily depends on neighboring and international suppliers, leaving the country vulnerable and insecure due to political and economic fluctuations. To overcome these challenges, Jordan must establish comprehensive policies and plans to achieve energy production, conservation, and sustainability. This case study explores Jordan's energy sources and security, highlighting strategies for long-term sustainable electrical energy development. The analysis focuses on addressing challenges, proposing alternative solutions, and advancing efficient plans for energy expansion. Key strategies include embracing renewable energy sources, enhancing conservation, and leveraging technological advancements to improve efficiency and a resilient energy sector.



***Corresponding Author:***

Emad Awada
Department of Electrical Engineering, Faculty of Engineering Technology, Al-Balqa Applied University
Amman 11134, Jordan
Email: emad.awada@bau.edu.jo

## 1. INTRODUCTION

As energy is essential for modern society, its availability and cost range affect every aspect of human life. In fact, at the end of the last century, energy supply and environmental destruction emerged as key elements in global sustainable development [1]-[3]. That is, issues such as fossil fuel prices reaching significant values, severe environmental impact, and resource dominance by a few countries [3]-[5] have driven researchers, policymakers, and planners to adopt new methods to secure energy for the following generation. In Kim *et al.* [6], while the International Energy Agency (IEA) defines energy security as the accessibility of resources at a reasonable price, the oil crisis in the 1970s had escalated oil prices and shifted European and American interests to the Middle East oil for security and stability [4]. As a result, the whole world has started looking into replacing conventional energy sources with new renewable sources. For example, as Jordan's energy future is affected directly by geopolitical instability and economic fluctuations, the ability to maintain energy security has been a critical issue. In the geopolitical uncertainty, Jordan faces considerable limitations in conventional resources, including crude oil, coal, and natural gas, which make the country susceptible to global energy market disruptions. According to Enerdata [7] and the Jordanian Ministry of Energy and Mineral Resources, Jordan imports 94% of its energy supplies from neighboring countries while its domestic demand continues to increase at 3% a year. Therefore, as energy demand

continues to rise, energy consumption is projected to accelerate sharply in the near future [8] with the risk of hindering supplies due to major political conflict in the rejoin [9]. In 2022, the Jordanian Ministry of Energy and Mineral Resources (MEMR) [10] published an annual report highlighting the primary sectors of energy consumption. The report has shown that the transportation, residential, and industrial sectors accounted for the top three energy consumers, with a combined total of 85% of the country's energy and 22% for the residential sector. Yet, due to ongoing population growth, this percentage is anticipated to increase rapidly [9]. Meanwhile, based on historical data provided by the National Electric Power Company (NEPCO) [11], the use of fossil fuels for power generation has been surging over the last two decades, which will limit the country's economic growth. In the latest published report for the MEMR, Jordan Energy Strategy 2020-2030, the primary energy forecasted demand between 2020 and 2030 is shown in Table 1. With an 8% increase by 2030, crude oil will form 51%, followed by natural gas with 25% of total projected fossil fuel energy consumption [10].

Table 1. Primary energy demand forecast (2020-2030) [10]

| Year | Primary energy demand (Overall domestic consumption) (toe) |
|---|---|
| 2020 | 10,039 |
| 2021 | 10,267 |
| 2022 | 10,420 |
| 2023 | 10,595 |
| 2024 | 10,668 |
| 2025 | 10,976 |
| 2030 | 11,760 |

According to the official reports from the Jordanian Petroleum Refinery [12], Jordan continues to rely heavily on imported crude oil, both now and in the foreseeable future. Interestingly, as noted by Momani [13], even when oil prices soared to $147 per barrel in 2008, this dependence on crude oil as the country's primary energy source remained unchanged. In Abu-Attieh *et al.* [14], natural gas and crude oil were the main energy sources utilized by Jordan in 2018. That is, up to 89% of the total energy mix in Jordan was based on imported natural gas and crude oil. Meanwhile, in Sandri *et al.* [15], imported fossil fuels continue to dominate Jordan's energy mix for 2020. Therefore, the nation's energy security is at risk due to global and local events. This situation worsens as the nature of demographic expansion arises. On the other hand, the influx of refugees from neighboring countries, such as Syria and Iraq, is placing an increasing burden as energy demand rises. Additionally, regional stability and disturbance may affect energy supplies. In 2011, an intentional explosive assault against the Jordanian and Egyptian primary gas feeder line that provided 88% of Jordan's supplies cost the country 4 billion JD for alternative sources to operate power plants [9]. Therefore, energy policy and security were re-examined, and alternative resources such as nuclear [15] and oil shale [10], [13] were reconsidered.

This case study will add to the literature on Jordan's energy security and sustainability in terms of policy, geopolitical treaties, environmental, and technological developments. By investigating the energy situation in Jordan, identifying key obstacles, and assessing energy source availability, this study intends to find the pathway to achieve sustainability and feasibility in electrical energy security.

## 2. METHOD

Environmental considerations, sustainable resources, governmental policy, and regulations will be investigated to conclude the frameworks that influence energy security, futures, and impact based on regional geopolitical factors and resource availability. As a critical aspect of this analysis, energy demand patterns, consumption trends, distribution networks, and alternative renewable energy resources will be addressed to highlight the Jordanian path to sustainable electrical energy. Aiming to transform Jordan's energy sector, governmental and private sector involvement is required to diversify energy sources, reform energy markets from traditional fossil fuels to renewable alternative resources, and implement new regulatory incentives. By investigating energy implications, environmental considerations, and projected future electrical consumption, the study will provide long-term electrical energy sustainability in Jordan.

### 2.1. Implications and developments

As Jordan's energy resources are very limited [9], in 2018, only 2204 thousand oil barrels were produced from oil shale [15]. Therefore, Jordan has and continues to rely on neighboring countries to fulfill its energy requirements. In terms of oil products, Jordan imports the majority of its demand from Saudi Arabia ($1.15 billion in 2022) and Iraq ($182M) [16]. Meanwhile, a large portion of natural gas is still

imported from Egypt to form an overall 96% of Jordan's energy market [17], [18]. As a result, this massive amount of imported fossil fuel has a serious impact on energy security and could lead to critical power disruptions due to political conflict.

### 2.2. Environmental considerations

As a proposed plan, the Ministry of Environment document for 2021 [18] emphasizes improving its obligation to international climate change by raising awareness, minimizing greenhouse gas emissions by 31% in 2030, and enhancing energy efficiency in all sectors by 9%. With 53,786.4 Mtons CO2eq global emissions, 34.54 Mtons CO2eq were produced by Jordan in 2022 to form 0.06 % globally [19], [20] with the ability to rise to 43.98 Mtons CO2eq in 2030 by doing business as usual [17], [21]. As a result, the national policy program and action have been initiated with the support of international assistance and funding. By adopting the Climate Change Policy—Paris Agreement (2013–2020), the government adopted rule number 79 for climate change to fully engage stakeholders and partners in the technical and decision-making processes. However, the bylaw is still not fully active and needs interpretation to enforce the Ministry of Environment regulation for a low-emissions strategy and attaining low-carbon sustainable economic growth.

### 2.3. Energy resources

In the ten-year plan strategy (2020-2030), the national energy sector controlled by the MEMR has laid the roadmap to self-sufficiency [16], [19]. Currently, the Jordanian energy market is composed of three major elements. That is, from higher to lower dependency, oil products come in first place, natural gas in second place, and renewable energy in third place for consumption and power generation. However, as part of its plan to improve efficiency and reduce emissions by 10% by 2030, the MEMR is looking to diversify fuel types by promoting natural gas by imposing a reduction of 16% to 7% in tax reliefs. Meanwhile, as renewable energy has shown significant growth in the last few years, renewable electricity power energy has risen to 13% in 2019 [16]. This increase came as a result of new policies and incentives provided by the government to support investments. Yet, in practice, the 13% contribution is still very low for the overall energy market in Jordan.

### 2.4. Population growth

In the last two decades, Jordan has experienced a rapid increase in population. With the instability in the Middle East, Jordan has been a haven for many refugees from Iraq and Syria. In the latest Department of Statistics report, the Jordanian population is around 11,642,859 [20]. As a result, the huge number of people living in Jordan demands a huge amount of energy daily. For instance, in Dar-Mousa and Makhamreh [22], the capital of Jordan (Amman) has the highest electricity consumption, with 36% of the total generated electricity. As a result of the significant impact of population growth, tension in neighboring countries, and global fluctuations in the oil market, Jordan's dependency on fossil fuels such as oil and natural gas could jeopardize energy security and the economy and increase global greenhouse gas (GHG) emissions based on high consumption [8], [9].

### 2.5. Electrical power and consumption

In terms of electrical power energy, Jordan's electrical peak loads and demands have experienced a substantial rise over the last decades and will continue to rise due to population growth and a major lifestyle change [10]. In fact, between 2000 and 2011, peak consumption grew from 1.200 MW to 2.650 MW, with an average of 8% a year. Meanwhile, from a power generation point of view [11], total generation doubled from 7.375 GWh to 14.390 GWh for the same period and 20 GWh in 2022. Yet in terms of natural resources, Jordan has a high dependency on imported energy, which has created significant challenges for the power sector in Jordan. With an energy mix of 58% oil and 21% natural gas used in electrical power generation in 2020, power disruptions are still a common factor due to poor financial conditions and the absence of venture resources. As a result, these challenges have led Jordan to plan various action for short- and long-term solutions, such as electrical exchange with neighboring countries, build a renewable solar power station plants in Ma'an and the Samara for an additional 600 MW, create extra crude oil storage in Aqaba to include six tanks holding 120,000 cubic meters, and assemble three domes for liquefied gas holding 11,000 cubic meters. In addition, attract investors such as Saudi Arabia for the possible construction of a 2.5-GW nuclear plant and the United Arab Emirates to build a wind plant with a 1-GW capacity and storage system [23]. Meanwhile, the electrical power consumption was examined based on consumer sectors. In Ayasreh *et al.* [8], historical data up to 2018 show that residential, industrial, and water pumping occupied the first three major consumers with 45%, 20%, and 14% respectively of Jordan's electrical power consumption. The higher percentage of residential electrical energy consumption can be related to a combination of elements with direct and indirect effects. For instance, climate change, building construction design, insulation, and human energy consumption

behaviors play substantial roles in unnecessary energy depletion or conservation. According to the NEPCO annual report for dwelling types' electrical consumption, in 2013, the total building electrical consumption was 43.02%, and this percentage increased to 45.12% in 2018. As a result, this increase in residential consumption has cost the national electrical company over 17 million Jordanian dinars [24], forcing decision-makers to take serious action to minimize energy consumption and arrange for a new source of electrical power.

Focusing on residential buildings in Amman, Jordan, three urban categories (single houses, apartments, and large houses) form this sector. That is, based on Monna *et al.* [25] for 2015, single houses, which construct 55% consume an average of 3600 kWh/year per house, apartment buildings form 42% with approximately 5400 kWh/year per apartment unit, and large houses (villa) forming 2.8% with an average of 9600 kWh/year per villa. Yet, residential electrical consumption is expected to increase by 30% in 2030 [11], [26]. However, as in Table 2 for Jordan's electrical tariff structure [11], charging per kWh increments from one tier to another as electrical consumption increases. This will lead to an average of 70 JD/month for the two largest residential types, single houses and apartment dwellings. Meanwhile, for the villa households, an average of 140 JD/month as charges per kWh shifted through the tariff tier rapidly.

Meanwhile, as the residential sector forms an important consumption sector, residential electrical consumption can be categorized by household appliances, where cooling, heating, and water heating collectively account for approximately 64% of residential electrical consumption [22].

As a result, a few practices can be recommended to conserve energy and cut down on cooling, heating, and water-heating electrical consumption, such as:

- Construct buildings with energy-star ratings to improve insulation.
- Use passive techniques in designing buildings, such as increasing shaded area, building orientation, and window-to-wall ratio.
- Use energy-saving appliances and implement and promote energy efficiency initiatives.
- Promote solar thermal water heaters.
- Promote renewable energy systems such as solar PV panels for low-cost renewable energy.
- Develop and enforce a sustainable energy policy and regulation.

Table 2. Jordan electrical tariff structure April 2022 [11]

| Consumption | Jordanian dinar (JOD)/kWh |
|---|---|
| 1–160 kWh/month | 0.042 |
| 161–300 kWh/month | 0.092 |
| 301–500 kWh/month | 0.109 |
| 501–600 kWh/month | 0.145 |
| 601–750 kWh/month | 0.169 |
| 751–1000 kWh/month | 0.19 |
| More than 1000 kWh/month | 0.25 |

## 3. RENEWABLE ENERGY AND TECHNOLOGY DEVELOPMENTS

Greenhouse gases, global warming, acid rain, and sulfur dioxide emissions are some of the side effects of conventional energy sources. Therefore, renewable energy sources have gained a lot of attention worldwide in electrical power generation [26], [27]. The advancement of solar and wind energy technologies has played a crucial role in expanding renewable energy and reducing reliance on fossil fuels. Recent progress in power electronics and drive control strategies has enabled the implementation of robust control techniques for multilevel inverters, minimizing harmonic distortion in the integrated grid while improving performance, reliability, power management, and energy efficiency, as demonstrated in [28]. Furthermore, innovations in solar photovoltaic (PV) storage systems have enhanced solar power utilization despite fluctuations in input voltage. Advanced DC-DC converters and inverters ensure a stable power supply during cloudy conditions, while robust sliding mode controllers continuously adjust duty cycles, as presented in [29]. On the other hand, with solar radiation of 5-7 kWh/m$^2$ a day and wind speed in the range of 7–11 m/s, Jordan can be considered one of the world's top solar and wind resources to form a strategic market for energy harvesting. In 2012, the MEMR, along with stakeholders, formed renewable energy policies and legislation (law #13) targeting 10% (around 1800 MW) of the overall electrical energy provided by renewable energy in 2020 [30], [31]. Fortunately, with the significant drop in renewable energy initial cost, it is projected to reach 50% of electrical power production in 2030 [32]. As a result, direct proposals for renewable energy projects have resulted in the formation of several enterprises. 28 corporations have signed energy acquisition agreements for solar energy projects with a total capability of 762 MW, and 8 corporations with a collective capacity of 539 MW for wind energy projects in the southern regions of Jordan [8].

Meanwhile, as renewable energy has to be directly tied in with the national power company (on-grid), instructions and regulations have been set up to control and dictate the deployment of renewable

energy. An outline and obligations of electricity purchasers and sellers, emphasizing that the sale of renewable energy should be made to licensed wholesale or retail providers through purchase agreements that follow the law. In the residential sector, extra restrictions have been applied in terms of qualifications, the amount of allowed power production (5.5 KW peak), and smart grid-metering technologies to optimize energy management [30]. On the other hand, as water heaters consume 15% of residential electrical energy, the MEMR passed a law in 2013 to enforce the installation of water heaters for residential dwellings larger than 150 $m^2$ to accommodate renewable rather than conventional energy. This law exempted small dwellings, less than 150 $m^2$, and businesses [10]. To expedite the economy in Jordan, the Finance Ministry passed a law to drop closing fees by 70% on residential dwellings between 150 $m^2$ and 120 $m^2$ and exempt units below 120 $m^2$. As a result, dwellings with 150 $m^2$ or more became less attractive to tenants; units consisting of solar heaters did not exceed 20% in Amman, and less than 10% of projected new constructions [10]. On the single-house side, which forms 55% of the residency, the majority have relied on the benefit of renewable energy modifications by replacing the conventional electrical water heater with a solar water heater, installing solar photovoltaic panels, and replacing conventional home appliances with energy-star-rated appliances for maximum energy conservation. That is, as technology advances, 7% of residential electrical power consumption can be eliminated by the new solar water heaters equipped with well-insulated water cylinders and capable of preserving water temperature for more than 72 hours. Meanwhile, in terms of the solar photovoltaic system, a standard residential system comes with 10 double-face monocrystalline panels, 2 m in height by 1 m in width each, and a 550-watt output. The system has a capability of 5.5 kW output peak on an ideal sunny day and perpendicular irradiation. As in Awada *et al.* [9], with an average 6 sun-hours time window, and 6.5 kWp/$m^2$ (average peak wattage for the year), daily energy production in kWh can be determined as in (1).

$$E = W_{\text{pv}} \times \text{PSH} \times \eta_{\text{sys}} \quad (1)$$

Where: $W_{pv}$ = array peak wattage, kWp; E = daily energy, kWh; PSHs = Average daily Peak Sun Hours of PV array operation; and $\eta_{sys}$ = system efficiency.

On a rooftop area of 20 $m^2$, an average of 8190 kWh/annual, and 682.5 kWh/month can be generated to cover typical single household and apartment consumption in normal conditions and turn out a minimum light bill of 12 JD (taxes 5 JD and holding fee 7 JD). For villas, a huge benefit can be attained through dropping to the first tariff tier, as purchase power will drop on average to 160 kWh/month with no holding and a 0.042 Jordanian dinar (JOD)/kWh tariff. Meanwhile, as in Monna *et al.* [25], the average effective rooftop area for solar PV installation is 126 $m^2$, 253 $m^2$, and 213 $m^2$ for single houses, apartment buildings, and villas, respectively, as in Table 3. Accordingly, these facts have suggested renewable energy space availability and the obligation of residential installation.

Table 3. Affected PV installation area for residential building rooftops [26]

| Building category | Single house | Apartment building | Large villa |
|---|---|---|---|
| Roof area | 155 $m^2$ | 300 $m^2$ | 250 $m^2$ |
| Staircase and shaded area | 29 $m^2$ | 47 $m^2$ | 37 $m^2$ |
| Effective PV insulation area | 126 $m^2$ | 253 $m^2$ | 213 $m^2$ |

## 4. RESULTS AND DISCUSSION

Due to its geographic location, fast population growth, and lack of conventional energy resources, Jordan is facing serious energy challenges and economic pressures. Mainly, with heavy dependence on imported oil and natural gas, over 98% of the total energy supply, energy prices fluctuate. As a result, serious questions arise: Are conventional fossil fuel supplies becoming rare and unsustainable for Jordan's economy? Should energy subsidies be explored? Are alternative energy resources needed for Jordan's energy security? And, what type of energy resources can be sustainable to develop inexpensive electricity in Jordan? As Jordan is exploring various options, including maximizing domestic energy sources and diversifying imports, the country has significant renewable energy potential, particularly in solar, wind, and biomass, providing an affordable, clean environment and economic growth. For instance, as water heaters consume 7% of the residential electrical power, the entire residential electrical power consumption can be reduced by enacting a law to install solar water heaters in each residential unit. Meanwhile, with available rooftop areas for solar PV installation, as in Table 3, section 3, a significant drop in national electrical power generation can be achieved by 45% of residential electrical power consumption. That is, on average, the minimum and maximum allowable residential solar PV systems installation range between 1 to 6 systems per single house, up to 12 systems per apartment building, and 1-10 systems per villa, as shown in Table 4. With this electrical

power generation, residential load can be covered and exceeded, as in section 2.5. In addition, the physical installation of solar PV will provide significant heating and cooling costs by increasing the shaded area (rooftop). Therefore, the national electrical power company can drastically save on residential electrical power consumption by enacting a law to invest in residential PV electrical generation.

Table 4. Max./Min. Solar PV electrical power generation based on the residential building rooftop area

| Building category | Effective PV area | Min. solar system units | Min. electrical power generation | Max. solar system units | Max. electrical power generation |
|---|---|---|---|---|---|
| Houses | 126 $m^2$ | 1 | 8190 kWh/annual | 6 | 49,140 kWh/annual |
| Apartment Bldg. with 10 apartments. units | 253 $m^2$ | 10 | 81,900 kWh/annual | 12 | 98,280 kWh/annual |
| Villa | 213 $m^2$ | 1 | 8190 kWh/annual | 10 | 81,900 kWh/annual |

As a result, to build a sustainable future and long-term energy strategy, Jordan must focus on upgrading infrastructure and expanding the legal and regulatory framework for renewable energy. However, achieving this goal requires collaboration between policymakers, engineers, technology developers, and investors. Unfortunately, political and economic short-sightedness has slowed technology transfer and stable energy planning. These obstacles make it harder for Jordan to achieve energy independence and can significantly impact the country's future energy strategy. To overcome these challenges, the government must introduce major incentives for upgrading electrical grid infrastructure, promoting solar water heater installations, and implementing a range of renewable energy projects in all sectors. Whether financed by the public or private sector, these initiatives will help alleviate Jordan’s energy crisis. Expanding renewable energy capacity will not only reduce reliance on imported oil but also ease the burden on power generation companies by decreasing fuel consumption. In similar case studies, in Aldhubaib [33], Saudi Arabia's energy policy was examined to highlight its challenges, particularly its heavy reliance on fossil fuels without alternative energy sources. With rapid population and economic growth, Saudi Arabia was the largest oil consumer in the Middle East and one of the highest globally, consuming approximately 3.5 million barrels per day. Meanwhile, in terms of electricity consumption, buildings accounted for 29% of total energy use, with per capita consumption steadily increasing. In response, decision-makers implemented significant measures to promote alternative, sustainable electricity generation. Given the country's high direct solar irradiance of up to 30 MJ/m² per day, Saudi Arabia's installed solar energy farm with a capacity reached nearly 440 MW in 2021 and set a plan for 58.7 GW of solar electrical power generation by 2030, which forms around 70% of the country's power generation. In another case, as in Akpan *et al.* [34], Zimbabwe's energy landscape was examined, highlighting the integration of renewable energy into the national grid. Alongside the existing hydropower generation capacity, photovoltaic (PV) systems have gained significant acceptance. These systems are being increasingly adopted to alleviate the load on the national grid and mitigate frequent power outages. Yet, despite the renewable energy substantial growth in the last few years, the adoption of renewable energy comes with challenges such as high Initial costs, power storage, power intermittency, grid integration, resource availability, and policy constraints [35]. That is, in countries with economic constraints and infrastructure limitations, the integration and transition to sustainable renewable energy systems could face barriers and hinder growth [35], [36]. For example, in Basit *et al.* [37], Countries with power generation that have traditionally depended on fossil fuel power plants, as baseload providers, will have low ramping rates and infrastructure to accommodate load fluctuations. Consequently, the integration of solar PV systems into the existing power network may introduce challenges in network reliability and stability, such as voltage imbalances, frequency fluctuations, and power flow disruptions. As a result, although the energy mix continues to grow, the integration between renewable and conventional energy networks remains an issue in many countries as the infrastructure must be updated [38]-[40].

## 5. CONCLUSION

With a population of over 9.5 million, the Hashemite Kingdom of Jordan is characterized as an oil-poor country in a disturbed region. Being dependent on external sources, Jordan has been forced to allocate around 25% of its gross domestic product (GDP) to the energy sector. Yet, any disturbance in the Middle East region directly affects Jordanian energy security. In today’s era of the highest level of energy prices, the size of the Jordanian energy market has doubled since 1990, with very limited local energy resources. With no obvious energy plans, either on a national scale or in Arab countries, different Jordanian sectors are planning their energy needs based on a general trend of energy supply and demand. The situation indeed needs a comprehensive plan to assess the impact of worldwide energy policy and Jordan's national energy security. Therefore, the need to diversify energy resources beyond traditional sources is required. Financial incentives, such as tax exemptions to enhance private initiatives in the field of renewable energy, are required

to enable renewable energy with long-term projects as promising energy sources. In addition, long-term power purchasing agreements need to be secured to establish a sustainable electrical price at a premium tariff over the cost of electricity generation, allowing the private sector to recover the costs of the project. In general, as the Hashemite Kingdom of Jordan is facing several pending challenges, such as meeting an increasing demand for energy supply, reducing emissions, and increasing energy supply security, the Jordanian law, regulations, and future energy strategies in terms of renewable energy must be expanded for extra future reliance and significant steps toward energy security and independence.

## FUNDING INFORMATION

Author states no funding is involved.

## AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

| Name of Author | C | M | So | Va | Fo | I | R | D | O | E | Vi | Su | P | Fu |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Emad Awada | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

## CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

## DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author, [EA], upon reasonable request.

## REFERENCES

[1] S. S. Alrwashdeh, "Energy sources assessment in Jordan," *Results in Engineering*, vol. 13, p. 100329, Mar. 2022, doi: 10.1016/j.rineng.2021.100329.
[2] O. Akinyemi, P. Alege, O. Ajayi, and H. Okodua, "Energy pricing policy and environmental quality in Nigeria: a dynamic CGE approach," *International Journal of Energy Economics and Policy*, pp. 268–276, 2017.
[3] Rajini K R Karduri, "Transitioning to tomorrow: the global journey towards a sustainable energy economy," *International Journal of Engineering Research & Technology*, vol. 12, no. 10, pp. 1–6, 2023, doi: 10.17577/IJERTV12IS100036.
[4] G. Abu-Rumman, A. I. Khdair, and S. I. Khdair, "Current status and future investment potential in renewable energy in Jordan: an overview," *Heliyon*, vol. 6, no. 2, p. e03346, Feb. 2020, doi: 10.1016/j.heliyon.2020.e03346.
[5] O. Saadeh, Z. Dalala, T. Niet, E. P. Ramos, and M. Howells, "Technoeconomic data adopted for the development of a long-term electricity supply model for the Hashemite Kingdom of Jordan," *Data in Brief*, vol. 30, Jun. 2020, doi: 10.1016/j.dib.2020.105391.
[6] J. Kim, F. Jaumotte, A. J. Panton, and G. Schwerhoff, "Energy security and the green transition," *Energy Policy*, vol. 198, p. 114409, Mar. 2025, doi: 10.1016/j.enpol.2024.114409.
[7] Enerdata, "Enerdata - Jordan Energy Report," [Online]. Available: https://www.enerdata.net/ (Accessed: Jul. 02, 2024).
[8] E. A. Ayasreh, M. Z. Bin Abu Bakar, and R. Khosravi, "The political concept of energy security: the case of Jordan," *Dirasat Human and Social Sciences*, vol. 44, no. 3, pp. 219–238, Sep. 2017, doi: 10.12816/0040578.
[9] E. Awada, E. Radwan, S. Abed, and A. Al-Mahrouk, "Economic analysis and design of sustainable solar electric vehicle carport at Applied Science Private University in Jordan," *Energies*, vol. 17, no. 17, p. 4321, Aug. 2024, doi: 10.3390/en17174321.
[10] Ministry of Energy and Mineral Resources (MEMR), "Performance of Jordanian mining sector during 2019-2021," *Local Report*. 2021. [Online]. Available: www.memr.gov.jo/ebv4.0/root_storage/en/eb_list_page/pofjmsd2021.pdf (Accessed: August 31, 2024).
[11] National Electric Power Company (NEPCO), "Annual reports." 2018, Amman, Jordan. [Online]. Available: https://www.nepco.com.jo/store/docs/web/2018_en.pdf (Accessed: July 31, 2024).
[12] Jordan Petroleum Refinery Co. LTD, "Annual report 2021." 2021, [Online]. Available: https://www.jopetrol.jo/ebv4.0/root_storage/en/eb_list_page/annual_report-2021-en.pdf (Accessed: Jul. 02, 2024).
[13] B. Momani, "Jordan, international financial institutions and social justice," no. October. 2020. [Online]. Available: https://library.fes.de/pdf-files/bueros/amman/16643.pdf (Accessed: July 02, 2024).
[14] S. Abu-Attieh, Z. Al-Omaria, and W. Emar, "Management and development of a residential energy storage system: a case study Jordan," *Journal of Applied Engineering Science*, vol. 20, no. 3, pp. 778–787, 2022, doi: 10.5937/jaes0-36314.
[15] S. Sandri, H. Hussein, and N. Alshyab, "Sustainability of the energy sector in Jordan: challenges and opportunities," *Sustainability*, vol. 12, no. 24, p. 10465, Dec. 2020, doi: 10.3390/su122410465.

[16] IRENA, "Renewable readiness assessment: the Hashemite Kingdom of Jordan," *International Renewable Energy Agency*, no. February. 2011.
[17] B. Schuetze and H. Hussein, "The geopolitical economy of an undermined energy transition: the case of Jordan," *Energy Policy*, vol. 180, p. 113655, Sep. 2023, doi: 10.1016/j.enpol.2023.113655.
[18] Jordan Ministry of Environment, "Updated submission of Jordan's 1st national determined contribution." 2021. [Online]. Available: https://unfccc.int/sites/default/files/NDC/2022-06/UPDATED SUBMISSION OF JORDANS.pdf (Accessed: Nov. 15, 2023)
[19] Ministry of Energy and Mineral Resources, "The executive action plan of Jordan Energy Strategy." 2020. [Online]. Available: https://www.memr.gov.jo/EBV4.0/Root_Storage/EN/EB_Info_Page/ActionPlanEN2020.pdf (Accessed: Nov. 15, 2023).
[20] Department of Statistics Jordan, "Population report 2024." Accessed: Jul. 19, 2024. [Online]. Available: https://dosweb.dos.gov.jo
[21] Emissions Database for Global Atmospheric Research, "GHG emissions of all world countries." 2023. [Online]. Available: https://edgar.jrc.ec.europa.eu/report_2023?vis=ghgtot#emissions_table (Accessed: Jul. 23, 2024).
[22] R. N. Dar-Mousa and Z. Makhamreh, "Analysis of the pattern of energy consumptions and its impact on urban environmental sustainability in Jordan: Amman city as a case study," *Energy, Sustainability and Society*, vol. 9, no. 1, 2019, doi: 10.1186/s13705-019-0197-0.
[23] N. W. Alnaser, H. M. Albuflasa, and W. E. Alnaser, "The transition in solar and wind energy use in Gulf Cooperation Council countries (GCC)," *Renewable Energy and Environmental Sustainability*, vol. 7, p. 4, Jan. 2022, doi: 10.1051/rees/2021034.
[24] CEIC, "Jordan electricity production view 1989-2023." Accessed: Jul. 16, 2024. [Online]. Available: https://www.ceicdata.com/en/indicator/jordan/electricity-production.
[25] S. Monna, R. Abdallah, A. Juaidi, A. Albatayneh, A. J. Zapata-Sierra, and F. Manzano-Agugliaro, "Potential electricity production by installing photovoltaic systems on the rooftops of residential buildings in Jordan: an approach to climate change mitigation," *Energies*, vol. 15, no. 2, p. 496, Jan. 2022, doi: 10.3390/en15020496.
[26] A. S. Khraiwish Dalabeeh, "Techno-economic analysis of wind power generation for selected locations in Jordan," *Renewable Energy*, vol. 101, pp. 1369–1378, Feb. 2017, doi: 10.1016/j.renene.2016.10.003.
[27] H. D. Ammari, S. S. Al-Rwashdeh, and M. I. Al-Najideen, "Evaluation of wind energy potential and electricity generation at five locations in Jordan," *Sustainable Cities and Society*, vol. 15, pp. 135–143, Jul. 2015, doi: 10.1016/j.scs.2014.11.005.
[28] V.-Q. Nguyen and T.-L. Le, "Flexible control with fuzzy observer-based sliding mode for multilevel inverter," *Journal of Electrical Engineering & Technology*, vol. 19, no. 7, pp. 4573–4586, Sep. 2024, doi: 10.1007/s42835-024-01878-9.
[29] E. Awada, E. Radwan, and M. Nour, "Robust sliding mode controller for buck dc converter in off-grid applications," *Bulletin of Electrical Engineering and Informatics*, vol. 11, no. 5, pp. 2425–2433, Oct. 2022, doi: 10.11591/eei.v11i5.3705.
[30] I. Marei, "Revisiting the regulatory framework: a necessary action to promote the deployment of renewable energy sources for electricity in Jordan," *Renewable Energy Law and Policy Review*, vol. 7, no. 1, pp. 44–57, Jan. 2016, doi: 10.4337/relp.2016.01.04.
[31] A. Abu-Dayyeh, "From energy mess to energy management: Jordan as a case study (2007-2020)." 2015. [Online]. Available: https://library.fes.de/pdf-files/bueros/amman/11188.pdf (Accessed: July 2, 2024).
[32] S. S. Alrwashdeh, F. M. Alsaraireh, and M. A. Saraireh, "Solar radiation map of Jordan governorates," *International Journal of Engineering & Technology*, vol. 7, no. 3, p. 1664, Aug. 2018, doi: 10.14419/ijet.v7i3.15557.
[33] H. A. Aldhubaib, "Electrical energy future of Saudi Arabia: challenges and opportunities," *Frontiers in Energy Research*, vol. 10, Dec. 2022, doi: 10.3389/fenrg.2022.1005081.
[34] J. Akpan, H. Kumba, and O. Olanrewaju, "Sustainable energy in Zimbabwe - status, challenges and solutions," *Renewable Energies*, vol. 2, no. 2, Jul. 2024, doi: 10.1177/27533735241276201.
[35] H. M. Saleh and A. I. Hassan, "The challenges of sustainable energy transition: a focus on renewable energy," *Applied Chemical Engineering*, vol. 7, no. 2, p. 2084, Apr. 2024, doi: 10.59429/ace.v7i2.2084.
[36] M. Sahoo and N. Sethi, "The intermittent effects of renewable energy on ecological footprint: evidence from developing countries," *Environmental Science and Pollution Research*, vol. 28, no. 40, pp. 56401–56417, Oct. 2021, doi: 10.1007/s11356-021-14600-3.
[37] M. A. Basit, S. Dilshad, R. Badar, and S. M. Sami ur Rehman, "Limitations, challenges, and solution approaches in grid-connected renewable energy systems," *International Journal of Energy Research*, vol. 44, no. 6, May 2020, doi: 10.1002/er.5033.
[38] H. B. Tambunan *et al.*, "The challenges and opportunities of renewable energy source (RES) penetration in Indonesia: case study of java-bali power system," *Energies*, vol. 13, no. 22, p. 5903, Nov. 2020, doi: 10.3390/en13225903.
[39] O. Sabishchenko, R. Rębilas, N. Sczygiol, and M. Urbański, "Ukraine energy sector management using hybrid renewable energy systems," *Energies*, vol. 13, no. 7, p. 1776, Apr. 2020, doi: 10.3390/en13071776.
[40] M. Tvaronavičienė, "Towards renewable energy: opportunities and challenges," *Energies*, vol. 16, no. 5, p. 2269, Feb. 2023, doi: 10.3390/en16052269.

## BIOGRAPHIES OF AUTHORS

**Emad Awada** received the B.S., M.S., and Ph.D. degrees in Electrical Engineering from Prairie View A&M University, USA, in 1998, 2006, and 2011, respectively. He is currently an associate professor at the Department of Electrical Engineering, Al-Balqa Applied University, Jordan. His research interests include power systems, renewable energy, energy conservation, mixed-signal systems, signal processing, and power fault detection. He can be contacted at email: emad.awada@bau.edu.jo.