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Physics-Based Modeling of Hybrid Solar–Nuclear Energy Systems: A Strategic Pathway for Sustainable Power in Saudi Arabia

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Abstract

As part of global efforts to reduce carbon emissions and diversify energy sources, the focus has shifted towards generating electricity from solar and nuclear power. This is a significant change in Saudi Arabia's energy landscape that is consistent with Vision 2030's environmental sustainability objectives. The objective of this research is to use physical modeling for hybrid solar-nuclear energy systems for sustainable . The results of the simulation using FORTRAN program showed that solar irradiance, cell temperature, and production efficiency have a dynamic connection. Power and irradiance are directly correlated also found to be directly correlated. On the other hand, efficiency and irradiance were shown to be inversely correlated. The results showed that nuclear power is the system's steady source since the amount of electrical power produced rises dramatically as the nuclear fission rate grows. The nuclear system is perfect for satisfying baseloads . The temporal integration between the two sources also reveals that the maximum contribution of solar power (125 MW) combined with nuclear stability (24 MW) allows the system capacity to reach 149 MW during peak hours (12 noon).

Keywords: Mathematical modeling; Electrical energy; Nuclear energy; Nuclear fission; Hybrid Solar–Nuclear Energy.

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1- Introduction

The sector of energy has been an exceptional transformation during the past few decades, which can be attributed to factors such as growing concern for climate change, rapid depletion of fossil fuel reserves, and increasing penetration of renewable energy resources [1-2]. At the same time, the escalating frequency of anthropogenic outages and the energy crisis arising from socio-political events have emphasized the need for improving the national energy security and resilience. In light of this, de-carbonization and diversification are the future paths chosen by the world's energy sector, and this is achieved by utilizing energy resources such as solar and nuclear energy that do not produce greenhouse gas emissions [3-5]. The latter, on the other hand, has led to a conceptual change in the energy sector [1]. Saudi Arabia must achieve the goals of Vision 2030, to achieve economic and environmental sustainability by diversifying energy sources and promoting a knowledge-based economy. In recent years, investments in renewable energy have garnered increasing global attention, driven by the need to achieve sustainable development policies encompassing economic, social, and environmental dimensions [4-5] . There is a strong relationship between energy consumption and development, as evidenced during the Industrial Revolution when production technology shifted from human labor to machinery, leading to increased use of coal to generate steam. Numerous studies highlight a significantly positive relationship between global growth and energy demand [3-4]. Future energy demand is expected to rise due to continued population and economic growth. Saudi Arabia's energy consumption is the highest in the Middle East, with an average oil consumption of approximately 4.3 million barrels per day (bpd) by the end of 2019, compared to an average of 4.1 million bpd in 2018 [6] . By the end of 2018, Saudi Arabia consumed around 289.9 terawatt-hours (TWh) of energy, representing a year-on-year increase of 0.42 percent compared to 2017. Due to high non-oil economic growth, population fertility, and desalination efforts, domestic energy consumption in Saudi Arabia remains exceptionally high The transition to renewable energy sources is a strategic imperative for Saudi Arabia as it seeks to achieve the goals of Vision 2030 [1-5], which emphasizes economic diversification and environmental sustainability. The motivation behind this study employs a physical approach based on modeling and current applications to analyze and develop ways for producing electricity from nuclear and solar energy [4-5]. It also examines how energy is now used in Arab nations, with Saudi Arabia receiving special attention because of its abundant natural resources and strategic potential in this area [4] . The present work developing an integrated mathematical and physical models that combines solar and nuclear systems to evaluate operational performance, efficiency, and power distribution over time, in line with Saudi Vision .

2- Growth of solar energy

Particularly in the European Union, solar energy has experienced remarkable growth driven by investments,technological advancements, and the global transition toward renewable energy sources (RES). According to the Ember Global Electricity Review report, solar power continues to expand rapidly worldwide [3-4]. At the present rate of growth, 593 GW of solar panels were installed in 2024, a 29% increase over 2023. This demonstrates the industry's continued expansion, even after a record 87% rise in 2023. About 292 GW of additional solar power had been put into service by the end of July 2024. More installations were made in 2024 than in 2023 in 11 of the 15 nations for which Ember monitors monthly capacity statistics [4]. From southern Europe to Central Asia, areas with high levels of insolation might be powered by solar energy, which is accessible practically anywhere the sun shines. However, it is fundamentally limited by its reliance on the time of day, season, and climate. Because of these characteristics, solar energy is less dependable than other energy sources, such nuclear power, figures (1,2) [4-5].

3- Nuclear power: reliability and efficiency

Despite growing competition from renewable energy sources, nuclear power is still a vital part of the world's energy balance. The International Energy Agency (IEA) predicts that in 2025 [3], the world's power production from about 420 nuclear reactors will set a new high. Currently, 10% of the world's electricity is produced via nuclear power. Currently, 63 reactors with a combined capacity of more than 70 GW are being built, which is one of the greatest numbers since 1990. More than 60 reactors, or roughly 15% of the world's nuclear fleet, have had their operational lifespans extended over the last five years. The international initiative Net Zero Nuclear, launched in 2023 at the World Climate Conference (COP28), aims to achieve climate neutrality, improve energy security, and support the expansion of renewable energy sources by tripling the world's nuclear capacity by 2050 [3]. Since 2020, annual nuclear energy investments—which include building new reactors and extending the life of existing ones—have risen by 50% to more than $60 billion. High stability and energy output are provided by nuclear power facilities. Unlike solar power plants, which have a capacity factor of 15–30%, nuclear power plants have an average capacity factor of 90–95%, enabling them to run continuously. The capacity factor is more than just a technical number; it is an important measure of productivity, profitability, and dependability that is used to manage energy balances and choose future technologies, figure (3) [3].

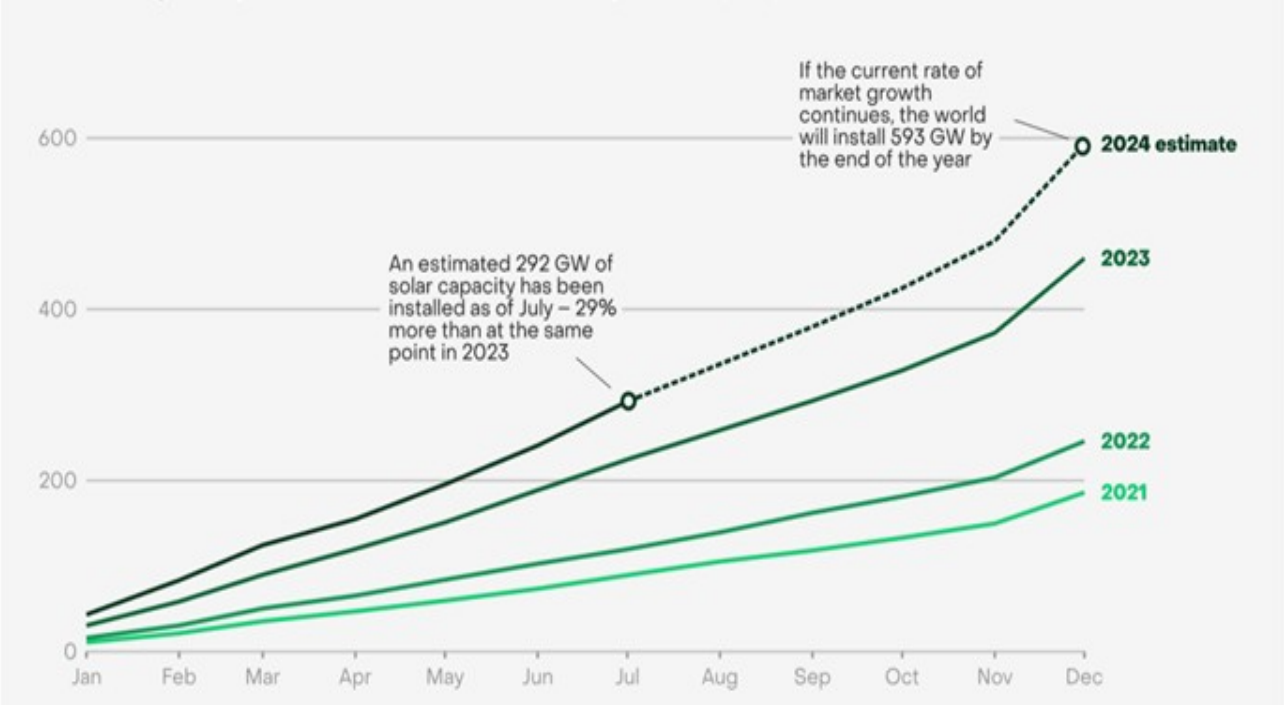


Fig.1. Global solar capacity growth year-to-date by month (GW) [3]

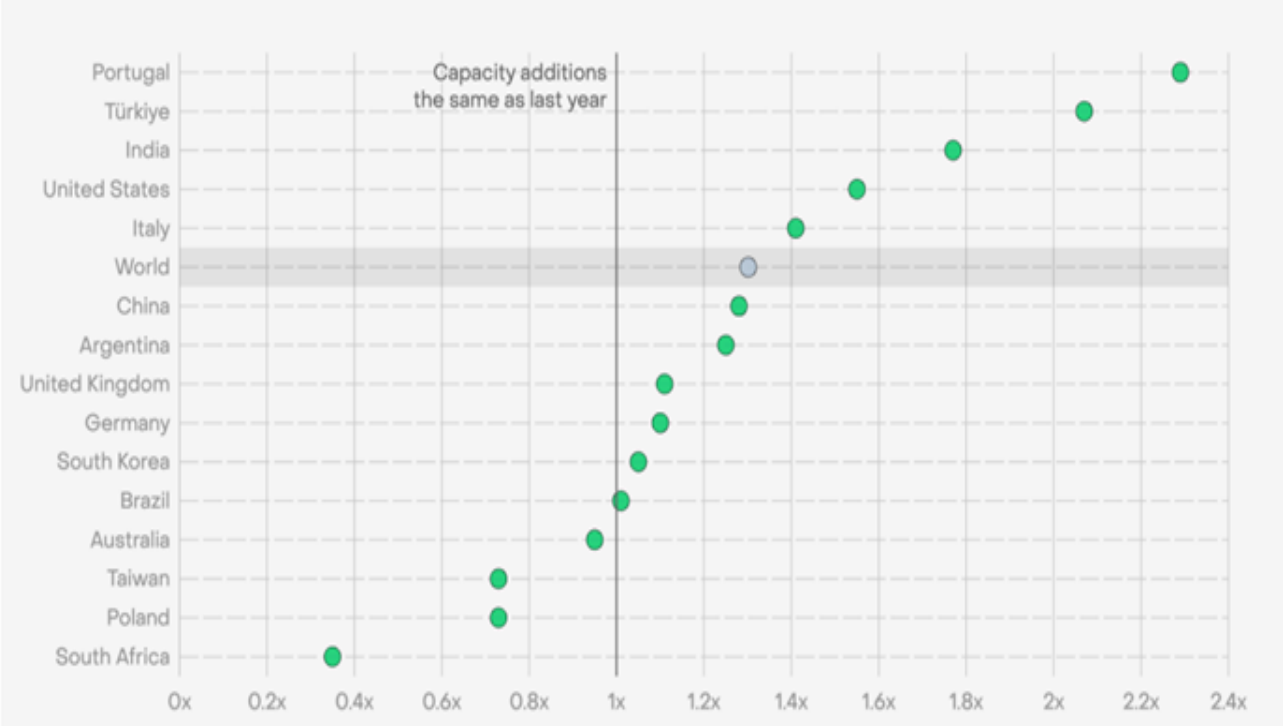


Fig.2. Ratio of production capacity growth in January-July 2024 to the same period in 2023 [3]

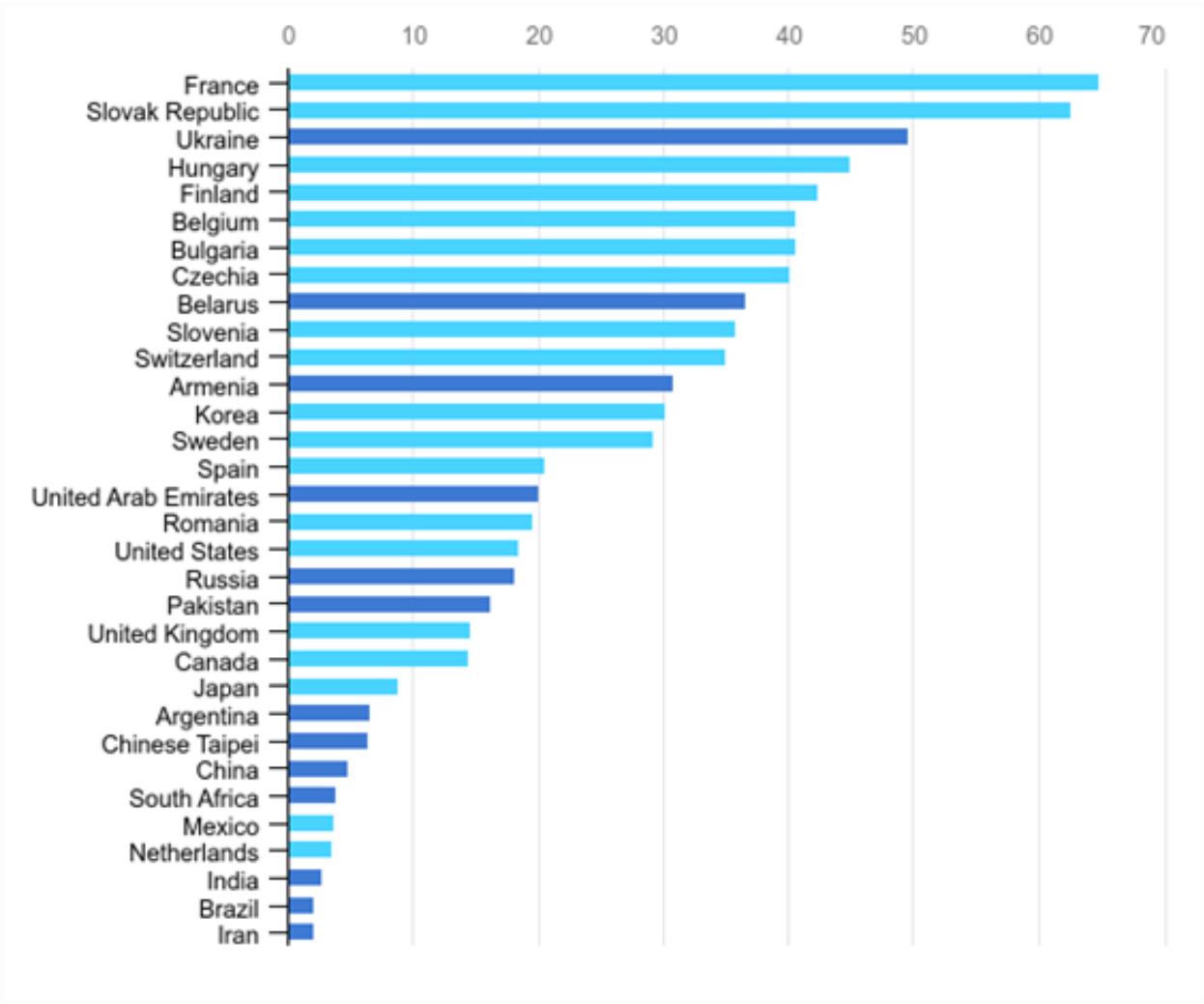


Fig.3. Share of nuclear power in total electricity generation by country, 2023 (IEA) [3]

4- Energy in Saudi Arabia

The Kingdom leverages its abundant sunshine ,benefiting from its vast desert expanses to develop large-scale solar energy projects , therefore Saudi Arabia has placed renewable energy at the core of its Vision 2030, aiming to diversify its economy and reduce its reliance on oil. Saudi Arabia's installed renewable energy capacity reached 2.8 gigawatts, with ongoing projects pushing this figure beyond 8 gigawatts , By the end of 2023, [4-5]. The Ministry of Energy targets generating 50% of the Kingdom's electricity from renewable sources by 2030, supported by significant expansions in solar and wind projects, investments in energy storage technology, and smart grids [6-8] . According to the Saudi General Authority for Statistics (Renewable Energy Statistics 2022), renewable projects are expected to generate 43,698 gigawatt-hours annually, supply electricity to 2.6 million homes, and reduce carbon dioxide emissions by approximately 24.8 million tons each year., is illustrated in Figure 4 and Figure 5 [9-12].

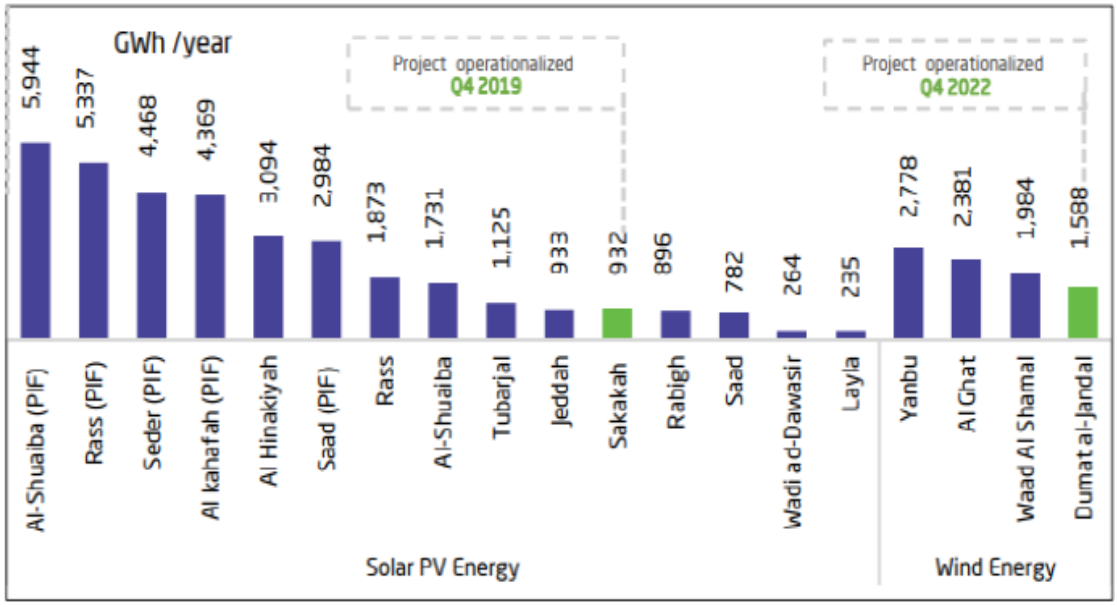


Fig.4. Electricity targeted to be generated from renewable energy projects annually. [Reference: Saudi General Authority for Statistics. (2022). Renewable Energy Statistics 2022 [12]

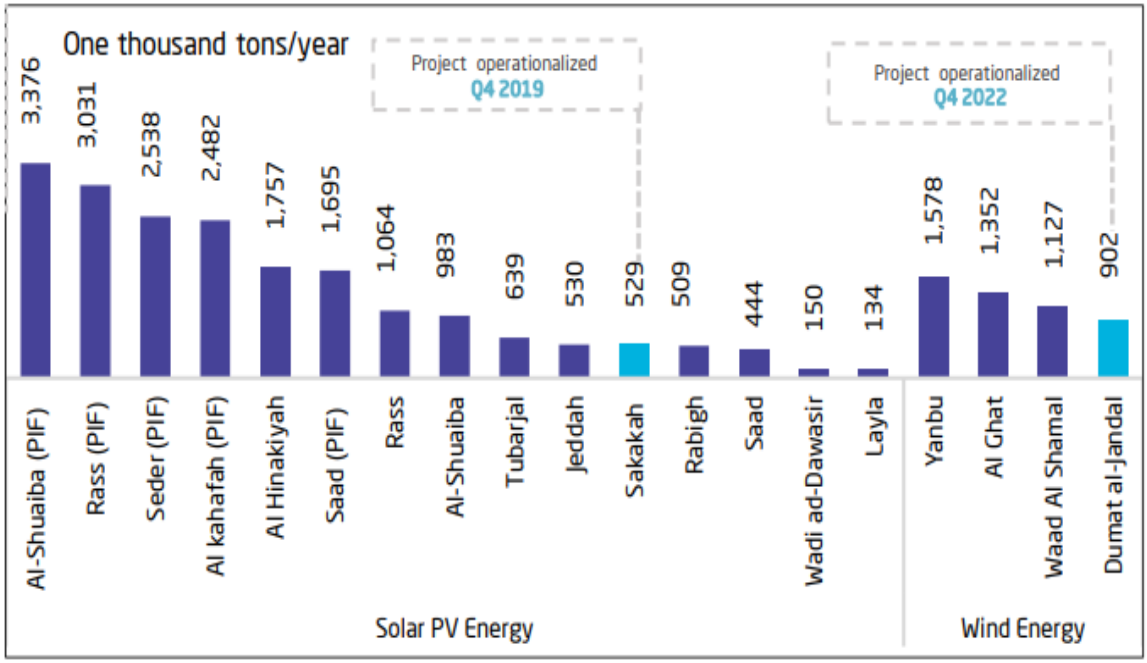


Fig.5. Expected environmental impact of projects on reducing carbon dioxide emissions. [Reference: Saudi General Authority for Statistics. (2022). Renewable Energy Statistics 2022[12]

5- Government Initiatives and Incentives

Under Vision 2030, Saudi Arabia is dedicated to changing its energy system and developing local capacity. To this end, it is providing a number of policy-related incentives to increase trade, draw in foreign direct investment, construct technology infrastructure, promote local employment, and strengthen local capabilities [10-11]. For instance, the Saudi Export Development Authority and the Saudi Export-Import Bank have established assistance systems for enterprises to get export finance. The Function of the Ministry of Investment by creating cross-governmental sectoral ecosystems and assisting businesses with their investment procedures, the Ministry of Investment is aggressively promoting opportunities in the green energy industry [12]. Saudi companies are building the groundwork for Saudi-Chinese cooperation by progressively integrating themselves into regional supply chains. For example, in 2011, Desert Technologies built the first solar PV manufacturing facility in Saudi Arabia, capable of producing 300 megawatts annually. Since then, the company has begun exporting its goods all over the world [13-15]

6- Energy Projects

6-1 KSA Energy (Solar)

Saudi Arabia's installed solar capacity has than doubled from prior years to 6.15 GW as of 2024. As part of its Vision 2030 plan to diversify its energy mix and lessen dependency on fossil fuels, Saudi Arabia is rapidly increasing its solar energy capacity [12- 13]. By 2030, the Kingdom hopes to produce 58.7 GW of solar energy, which will help it reach its target of obtaining 50% of its electricity from renewable sources, as given in Table.1 [28].

Table.1. Major Solar Projects in KSA [28]

Project Name	Location	Capacity (MW)	Key Features	Investment	Operator / Developer
Sakaka Solar Power Plant	Al Jouf	300	1.2 million solar panels over 6 km^2; powers 55,000 homes; reduces 530,000 tons of CO_2 annually	Over $292 million	Ministry of Energy under Custodian of the Two Holy Mosques Initiative

Shuaiba 1 Solar Project	Jeddah	600	Lowest energy purchase cost in KSA (~$0.0104/kWh); improves energy efficiency	2.37 billion USD	ACWA Power (35.01%), Badeel (34.99%), SAPCO (30%)
2024 Solar Expansion	Various (5 sites)	3,751 (combined)	Five new plants; part of 15 GW solar & wind expansion by 2027–2028	18.3 billion SAR (~$5.3 billion)	ACWA Power

6-2 KSA Energy (Nuclear)

Nuclear energy is an important part of Saudi Arabia's future energy mix, even though it now makes up 0% of the country's electricity production. As part of its Vision 2030 plan to diversify its energy mix, lessen its dependency on fossil fuels, and create a sustainable, knowledge-based economy, Saudi Arabia is actively expanding its nuclear energy sector [28]. In order to promote sustainability, energy security, and economic diversification, the Saudi National Atomic Energy Project (SNAEP) seeks to deploy peaceful nuclear energy, Table (2) [16-20] [28].

Table. 2. Key Nuclear Projects and Initiatives.[28]

Project / Initiative	**Purpose / Focus**	**Key Features**	**Status / Partners**
Low Power Research Reactor (LPRR)	Research, training, and development	First nuclear reactor in KSA; inaugurated in 2018; supports Vision 2030 by building local expertise	Developed by KACST & KA-CARE
Saudi National Atomic Energy Project	Electricity generation, human capital development, localization of technology, safety regulation	Focuses on building nuclear power plants; developing workforce; establishing regulatory frameworks	National initiative under Vision 2030
International Collaboration	Compliance and global partnerships	Works with IAEA; hosting the 2025 International Conference on Nuclear and Radiological Emergency Preparedness	Partnership with IAEA; global engagement

7- Challenges of Solar Energy in Saudi Arabia

Early solar development was hindered by unclear governance and fragmented responsibilities among ministries in Institutional Fragmentation (Pre-2016). The 2016 restructuring helped unify oversight under a single ministry. Under the skilled labor shortage, there is a lack of trained professionals in solar technology, which limits the pace of deployment and maintenance [28]. Under the limited local manufacturing capacity, Saudi Arabia's solar ambitions require high local content, but current domestic manufacturing capacity for PV components like float glass and aluminum is insufficient. In grid integration and storage, integrating intermittent solar power into the national grid requires advanced infrastructure and energy storage solutions .In environmental and land use constraints, large-scale solar farms may face land use conflicts and environmental concerns, especially in ecologically sensitive areas. [21-23] [28].

8- Challenges of Nuclear Energy in Saudi Arabia

In light of the field of regulation and safety, Saudi Arabia works to develop robust regulatory bodies and safety protocols to meet international standards for nuclear energy deployment. In terms of human capital and skills, the rate of development and safe operation are constrained by the lack of qualified professionals and nuclear engineers [28]. In addition to the infrastructure and investment requirements—long-term, expensive investments and complex infrastructure for nuclear power plants can be a barrier to rapid deployment—public perception and societal acceptance of nuclear energy also face skepticism and concerns about safety, waste management, and environmental risks. International compliance and oversight complicate matters and necessitate diplomatic cooperation with Saudi Arabia in order to match their plans with international treaties and IAEA protocols [24-28].

9- Methodology

9-1- Generating electricity from solar cell

A solar cell, often known as a photovoltaic (PV) cell, is a non mechanical device that directly generates energy from sunshine. Certain photovoltaic cells are capable of producing power from artificial light. Photons, or solar energy particles, make up sunlight. The varied wavelengths of the solar spectrum are represented by the different quantities of energy contained in these photons. Semiconductor material makes up a photovoltaic cell. Photons that hit a photovoltaic cell will either be absorbed by the semiconductor material, pass through the cell, or reflect off the cell. The only photons that can produce electricity are those that are absorbed. Electrons are separated from the atoms in the semiconductor

material when it absorbs sufficient solar energy [28-29]. The PV cell's front surface is made more responsive to the dislodged, or free, electrons during the manufacturing process, allowing the electrons to naturally migrate to the cell's surface. There is an electrical charge imbalance between the front and back surfaces of the PV cell due to the migration of electrons, which are all negatively charged, toward the front surface. The voltage potential that results from this imbalance is comparable to the positive and negative terminals of a battery. Electrons are absorbed by the PV cell's electrical conductors .Electricity flows through an electrical circuit when its conductors are connected to an external load, such a battery , as shown in figure 6 [29].

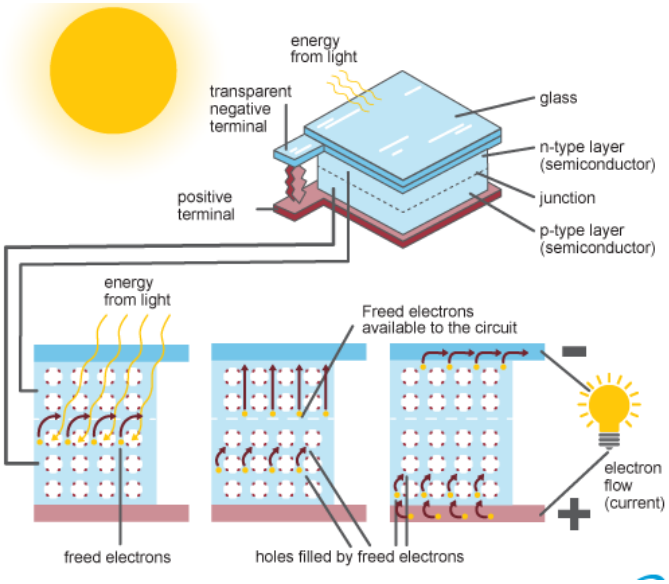


Fig.6. Generating electricity from solar cell [29]

9-2- Generating electricity from nuclear power

Nuclear fission, which is based on the energy produced when heavy atoms, such as ^{235}U , split, is how nuclear power plants produce electricity [30]. It happens when an atom is struck by a neutron, splitting it and starting a chain reaction that releases other neutrons. Heat is produced as a significant amount of energy by this atom-to-atom multiplication. After cooling, this heat produces steam, which powers turbines that are connected to alternators to produce electricity. Nuclear power plants operate through the following stages: [30-31]:

- The main circuit: tiny enriched uranium pellets are inserted into metal tubes called rods at the reactor's core. The primary circuit is formed by submerging these tubes in a water tank. The water in this circuit heated to 320°C due to the fission of uranium atoms. To keep the water liquid, pressure is applied to it. [30]

- The secondary circuit uses a steam generator to heat the water in the secondary circuit using hot water from the primary circuit. Steam turbines, which run an alternator to produce energy, are powered by the steam generated. [31]

- Voltage boosting: a transformer is used to raise the voltage of the resultant electric current to between 225,000 and 400,000 volts. This makes it possible to move electricity over the power system more effectively. [30-31]

- The cooling circuit converts steam from the secondary circuit back into water by cooling it. This is accomplished by means of a condenser, which can be supplied with air-cooled towers or cold water drawn from rivers or the sea. [30-31]

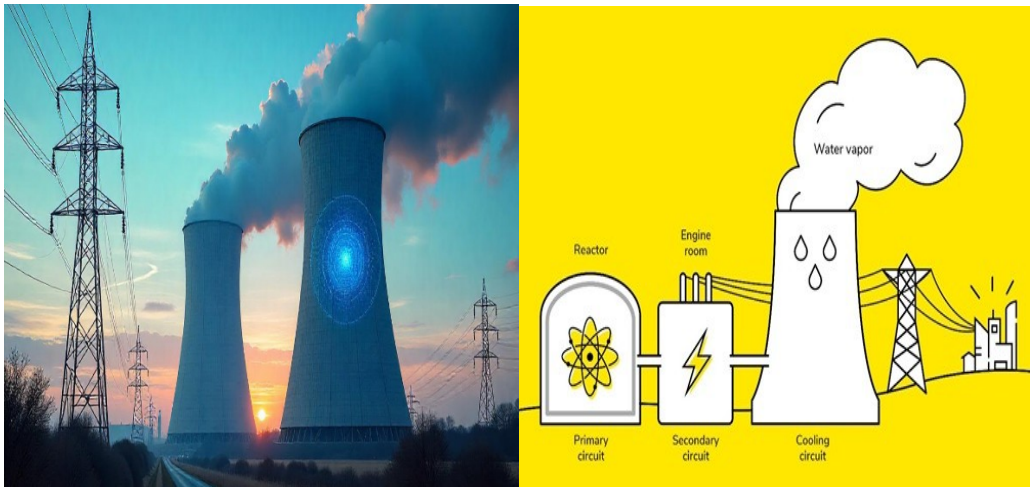


Fig.7. Generating electricity from nuclear power [31]

9-2-1- The phenomenon of nuclear fission

When a neutron strikes an unstable, heavy atom, fission takes place. The atom splits into two lighter atoms as a result of the collision.

This process is referred to as a chain reaction because it produces a significant and steady amount of energy and continuously triggers further atom fissions [51].

^{235}U is the fuel used in this procedure. Its physical characteristics and composition make it ideal for the fission process. When a neutron strikes the atomic nucleus of ^{235}U, it can split in two , figure (8). Fission products including Ba, Kr, Sr, Cs, I, and Xe with atomic weights ranging from 95 to 135 are

produced by the fission reaction in ^{235}U. Typical reaction products include the following examples [30-31] [51]:

$$^{235}U + n ===> {}^{144}Ba + {}^{90}Kr + 2n + 200\ MeV \quad (1)$$

$$^{235}U + n ===> {}^{141}Ba + {}^{92}Kr + 3n + 170\ MeV \quad (2)$$

$$^{235}U + n ===> {}^{94}Zr + {}^{139}Te + 3n + 197\ MeV \quad (3)$$

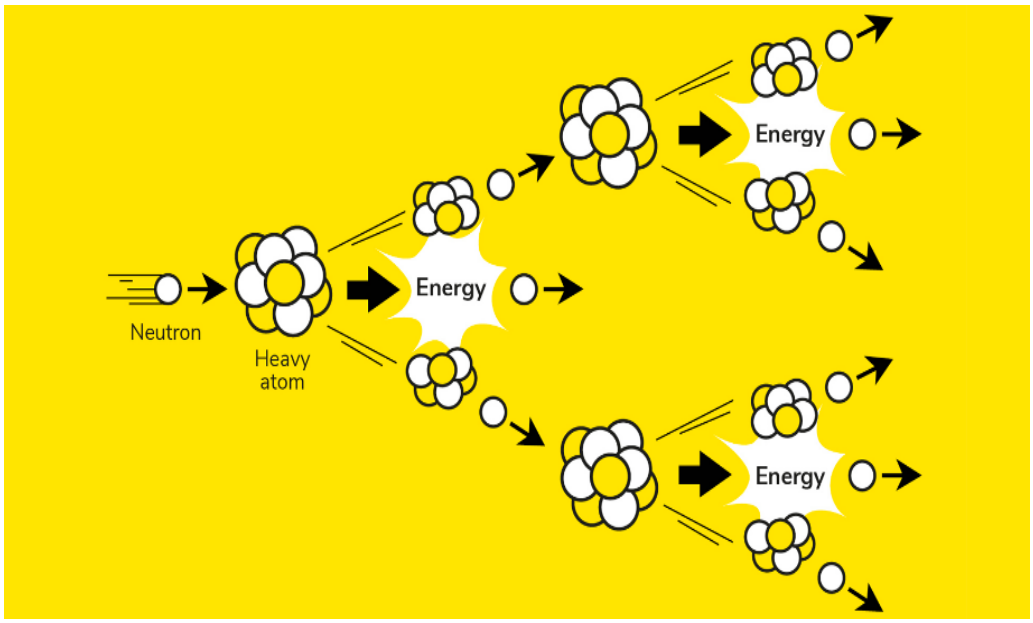


Fig. 8. show phenomenon of nuclear fission[31]

9-3 Mathematical Model

In order to investigate and assess the performance of solar and nuclear power generating systems in a dynamic hybrid system, this study relies on the development of an integrated physical-mathematical modeling framework. The three primary stages of the process are individual system modeling, numerical simulation, and hybrid system analysis [32-39] [41-50].

9-3-1- Solar PV Modeling

A model based on energy balance and thermoelectric relationships was used to describe the performance of photovoltaic cells [41-50]. The output power was computed as a function of temperature, loss coefficients, and radiation intensity. The NOCT model was used to model the cell temperature as a function of ambient temperature and sun irradiation, enabling a dynamic depiction of

the thermal effect. To get a realistic performance estimate, reference efficiency coefficients and system losses (such as wiring and inverter losses) were also considered [44]. Solar irradiance fluctuations were taken into account as a time-varying input to model system attitude throughout the day, and standard values for the coefficients were assumed based on literature [45] , The crystalline silicon (C-Si) photovoltaic technology was considered in the current simulation due to its extensive commercial use and typical temperature coefficient value (β≈0.004/◦C), which is in line with values documented in the literature [34] , and reference efficiency (ηref≈18%) are consistent with typical values reported for commercial crystalline silicon photovoltaic modules [34] .

$$P_{in} = A\ G \tag{4}$$

$$T_c = T_{amb} + \left(\frac{NOCT - 20}{800}\right)\ G \tag{5}$$

$$\eta = \eta_{ref}\ \left[1 - \beta\left(T_c - T_{ref}\right)\right] \tag{6}$$

$$P_{solar} = \eta\ A\ G\ \eta_{inv}\ \eta_{los} \tag{7}$$

Where

- Pin: Input solar power (W).
- Psolar: Electrical power output from the PV system (W).
- A: Solar panel area (m²).
- G: Solar irradiance (W/m²).
- Tc: Cell temperature (°C).
- Tamb: Ambient temperature (°C).
- Tref: Reference temperature (25 °C).
- η: Actual PV efficiency.
- ηref: Reference efficiency.
- β: Temperature coefficient (≈ 0.004/°C).
- ηinv: Inverter efficiency (≈ 0.95).
- ηloss: System efficiency after losses (≈ 0.85–0.9).
- NOCT: Nominal Operating Cell Temperature (~45°C).

9-3-2- Nuclear Energy Modeling

The physics of nuclear fission is used to describe energy generation in nuclear reactors , A full-scale commercial nuclear power plant (500–1600 MW) is not meant to be represented by the reactor taken into consideration in this simulation. Rather, the modeled system is equivalent to a modular or small-scale research reactor design with a continuous heat output of roughly 24 MW. This scale was specifically chosen to assess the suggested hybrid system's thermodynamic behavior and energy-management capabilities under regulated operation circumstances. Therefore, rather than being a commercial utility-scale reactor, the chosen reactor capacity is suitable for modeling purposes and should be understood as a representative small nuclear energy source. The power generated is correlated with the rate of fission and the energy released from each reaction, including the effectiveness of thermal and electrical conversion [46]. According to the model, the nuclear system runs in a semi-steady state, and its high capacity factor indicates continuous operation. Based on established operating data, standard values for the energy generated by fission (~200 MeV per fission) and conversion efficiencies were also applied [41-50].

$$P_{nuclear} = \eta_{th} \times \eta_{el} \times N_f \times E_f \times \mathrm{CF} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

Where

η_{th} :- Thermal efficiency (heat to steam conversion) (~0.33–0.37)

η_{el} :- Electrical efficiency (turbine and generator) (~0.33–0.36)

Nf:- Number of fissions per second

Ef: - Energy released from the fission of a single nucleus (~ 200 Mev (3.2×10^{-11} J))

CF: Capacity Factor (≈ 0.9)

9-3-3 -Hybrid System Modeling and Model of overall system efficiency

A time-dependent model was developed to integrate the outputs of the solar and nuclear systems, where the dynamic load distribution is thought to affect the overall system capacity [41-45],The interaction between the various sources is reflected in this model, where [46-48]:

•One variable source that varies over time is solar energy.

• A steady base load is represented by nuclear energy.

• To increase system stability, backup and storage variables were included [49].

$$P_{total}(t) = P_{solar}(t) + P_{nuclear}(t) - P_{storage}(t) + P_{\text{backup}}(t) \text{.....(9)}$$

- In order to concentrate on the direct relationship between solar and nuclear power generation, energy storage and backup terms were ignored in this simplified simulation framework, therefore the equation (9) become equation (10) :-

$$P_{total}(t) = P_{solar}(t) + P_{nuclear}(t) \text{.....(10)}$$

$$\eta_{ref} = \frac{p_{total}}{p_{solar} + p_{nuclear}} \text{.....(11)}$$

Where

P_{solar} (t): Variable (day/night)

$P_{nuclear}$ (t): Approximately constant

$P_{storage}$ (t): Energy storage (batteries)

P_{backup} (t): Backup when needed

9-3-4 - Numerical Simulation

The simulation was performed using hypothetical data reflecting realistic operating conditions, where the following were performed:

• The intensity of solar irradiation was was varied within a range of 600–1000W/m².

• The temperature of the cell was computed dynamically. [47]

• The impact of losses and efficiency coefficients on power output was examined.

• The reaction of the system was examined at various times (day and night) [49]

.• A number of measures, such as output power and overall system efficiency, were used to assess system performance. [50]

• Sensitivity analysis was used to assess how important factors like temperature, conversion efficiency, and capacitance coefficient affected the system's overall performance[50].

It should be mentioned that the performance of a single typical solar module with an effective area of one meter is represented by the results shown in Table (3). As a result, the output power values between (77 and 121 W) show unit-area performance in different irradiance scenarios. On the other hand, a utility-scale photovoltaic installation included into the hybrid energy system is represented by the solar contribution shown in Table (5). The single-module output was scaled to a total PV array area typical of large commercial solar farms in order to acquire the megawatt-scale solar power numbers.

10- Results and Discussion

Evaluation of the performance of the photovoltaic solar energy system The photovoltaic system's reaction to the surrounding environmental factors is depicted in the simulation results shown in Table (3) and Figures (9, 10, 11) (Figure 9): The extracted electrical power and solar radiation intensity was found to be linearly correlated; at a peak irradiance of 1000 W/m², the power increased from 77.18 W to 121.36 W [48]. The enhanced photon current produced within the semiconductor material is physically explained by the higher flux of incident photons [43]. The thermal effect (Figure 10): The cell registered 53.75 °C at 600 W/m² and 66.25 °C at 1000 W/m². The results showed a consistent rise in cell temperature with increasing irradiance intensity. The reason for this increase is that part of the solar energy is absorbed by the cell and transformed into heat rather than electricity. Conversion efficiency (Figure 11): The investigation revealed that when the temperature rose, the cell efficiency decreased from 0.159 to 0.150, or around 6% of its total value [44]. This is explained scientifically by the fact that an increase in temperature causes the open-circuit voltage to drop and the charge recombination rate to rise, both of which have a detrimental effect on the photovoltaic conversion's overall efficiency [54]. Analysis of the Performance of the Nuclear Power System: The relationship between the fission rate and the generated power was observed in Table (4) and Figure (12): Energy Density and Production Stability: The findings demonstrate a direct correlation between the nuclear fission rate per second and the electrical power produced [47]. The generated power was 10.6 MW at a fission rate of 3.00 E+18 and 31.7 MW at a rate of 9.00 E+18The tremendous energy density of uranium, which yields about 200 MeV every fission cycle, is responsible for this considerable rise [49]. This system is perfect for effectively covering baseloads with constant operational stability because of its independence from climatic circumstances. Table (5) and Figure (13), which show the combined 24-hour operational performance of the two systems and represent their dynamic integration, provide an analysis of the integrated solar-nuclear hybrid system's performance: Daytime Peak Period: With 125 MW from the solar system and 24 MW from the nuclear system, the system reached its maximum overall capacity of 149 MW at 12:00 PM. Here, solar energy plays a crucial role in supplying the substantial rise in demand during the day. Evening and Night Periods [50]: The nuclear system's function as a safety valve for the hybrid system is amply illustrated; at 9:00 PM and 6:00 AM, solar production completely stops (0 MW), while the nuclear system continues to produce a steady 24 MW of power [50], As a result, the study's conclusions are generally in line with recent developments in the scientific literature [52-56]. Note that the simulation results show instantaneous power production under particular operating conditions, whereas the published national solar capacity relates

to installed capacity [13] . And a small modular/research reactor with an approximate thermal power output of 24 MW serves as the basis for the simulation parameters [57].

Table (3): Simulation Results using hypothetical data of Solar energy model

Parameters	Symbol	Unit	Value/Range
Fixed Parameters			
PV area	(A)	m^2	1
Reference temperature	T_{ref}	°C	25
NOCT	NOCT	°C	45
Reference efficiency	η_{ref}	%	18
Inverter efficiency	η_{inv}	–	0.95
System-loss factor	η_{loss}	–	0.85
Temperature coefficient	β	$°C^{-1}$	0.004
Ambient temperature	T_{amb}	°C	35
Variable Conditions			
Solar irradiance	(G)	W/m^2	600–1000
Calculated Results			
Cell temperature	Tc	°C	53.75- 66.25
Actual efficiency	η	–	0.159-0.150
Output power	P_{out}	W	77.18-121.36

Table.4. Simulation Results based on hypothetical data of Nuclear energy model

Parameter	Symbol	Unit	Value/Range
Fixed Parameters			
Thermal Efficiency	η_{th}	-	0.36
Electrical Efficiency	η_{el}	-	0.34
Fission Energy	E_f	(J/fission)	(200 Mev) (3.2×10^{-11} J)
Capacity Factor	CF	-	0.9
Variable Conditions			
Fission Rate	Nf	(fissions/s)	3.00E+18 – 9.00E+18
Calculated Results			
Output power	P_{out}	W	1.06E+07- 3.17E+07

Table.5. Simulation Results using hypothetical data of Hybrid Model

Time (h)	G	Solar Power (MW)	Nuclear Power (MW)	Total Power (MW)
06:00	0	0	24	24
09:00	400	50.73	24	74.72
12:00	1000	125	24	149
15:00	900	110.87	24	134.86
18:00	200	24.27	24	48.27
21:00	0	0	24	24

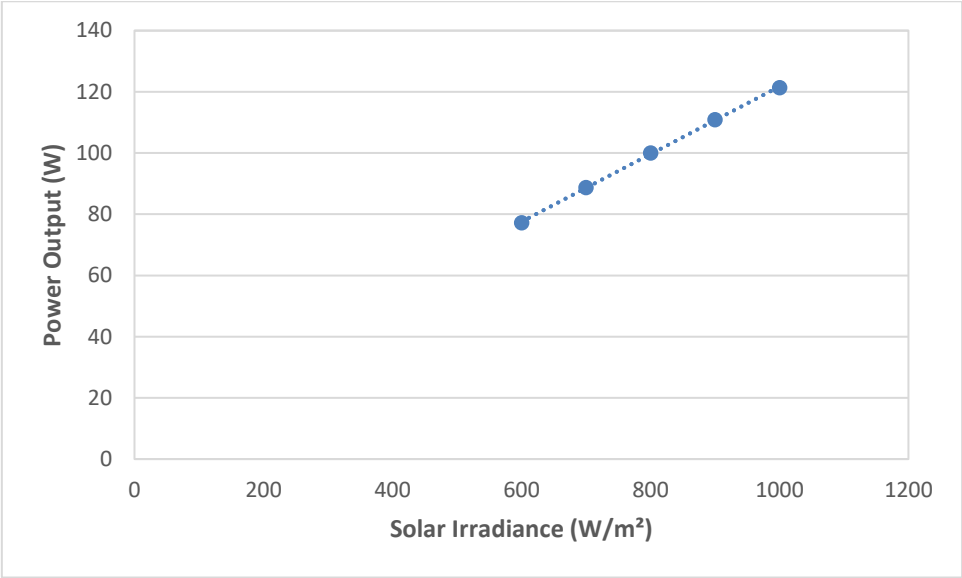


Fig. 9. Explains Solar Irradiance relation with Power Output

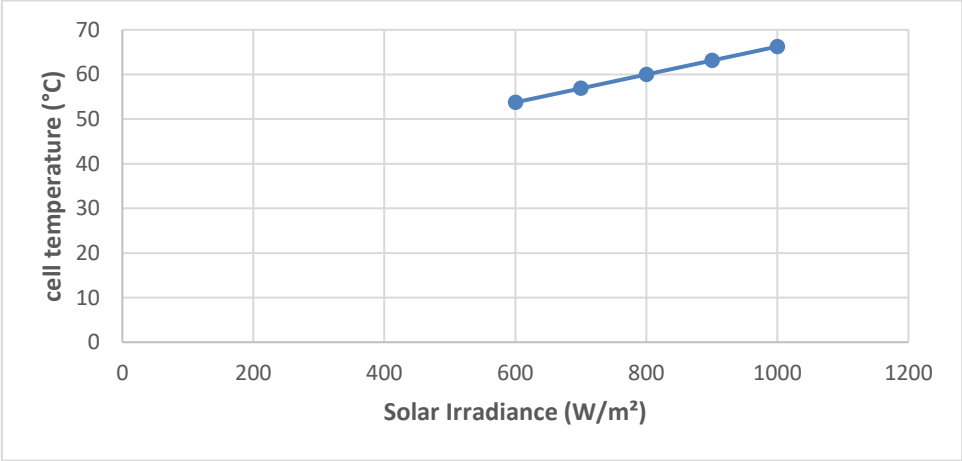


Fig. 10. Shows relation Solar Irradiance with Cell temperature

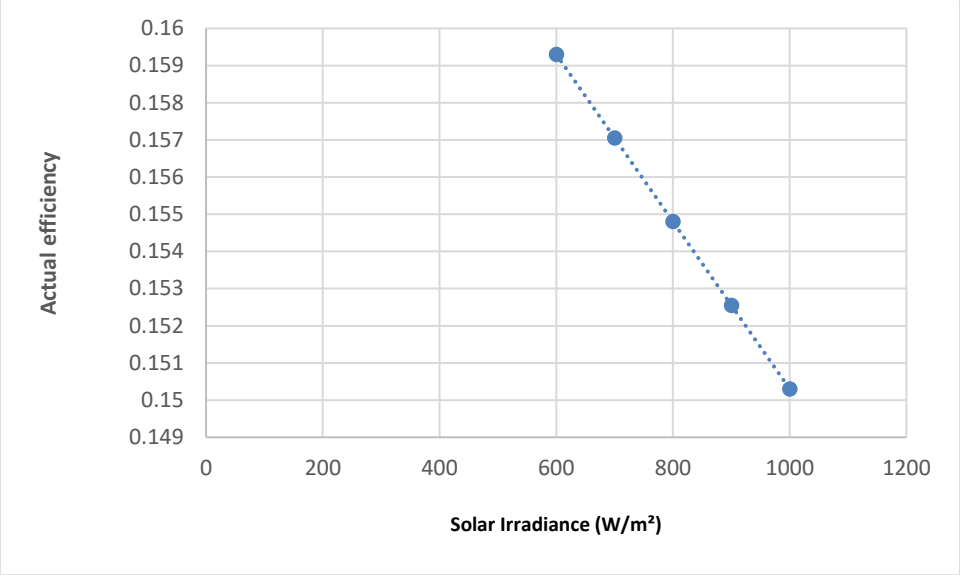


Fig.11. Shows the relation between Solar Irradiance and Actual **efficiency**

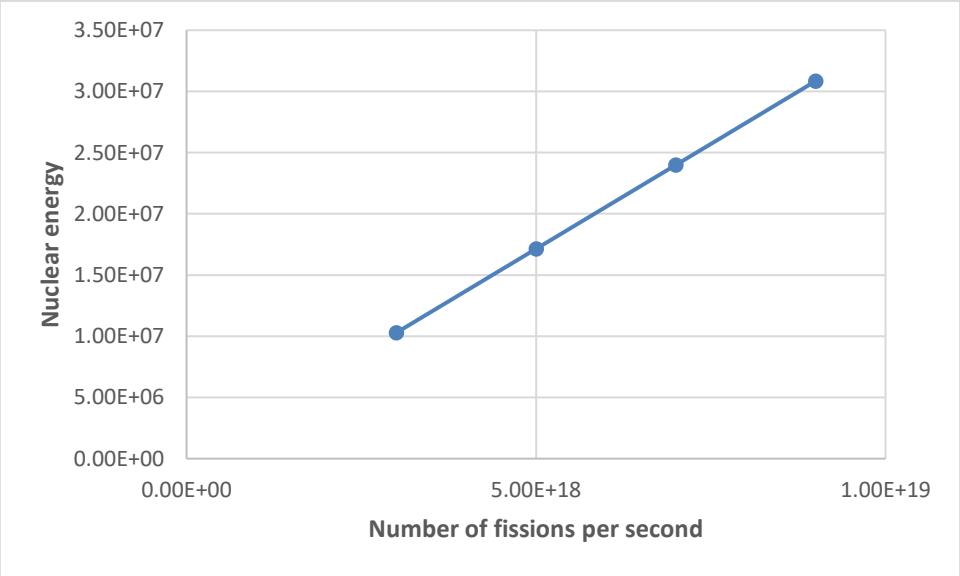


Fig. 12. Explains the relation between Number of fissions per second and Nuclear energy

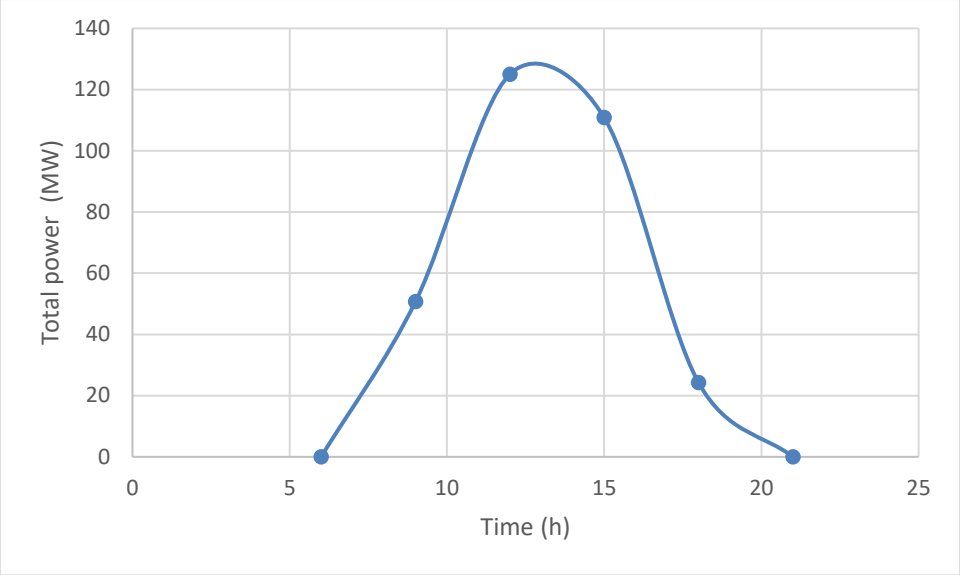


Fig. 13. Shows the relation time with total power

11. Conclusion

The results of this study explain that integrating solar and nuclear energy within a hybrid system offers an efficient and stable solution to meet the growing electricity demand in Saudi Arabia, while simultaneously improving grid reliability and reducing carbon emissions. Simulations showed that relying on a balanced mix of solar and nuclear energy achieves greater operational stability compared to relying on a single energy source.The analysis indicates that the ideal solar-to-nuclear power ratio for Saudi Arabia's climate is about between 60:40 and 70:30. While nuclear energy offers consistent base capacity to ensure the continuity of electricity supply during times of low solar irradiation or increasing demand, solar energy helps cover daytime loads and reduce fuel consumption. Also it is indicate that integrating these hybrid systems requires developing smart grid infrastructure, enhancing energy storage technologies, and improving load management strategies to ensure the stability of the national electricity grid. This integration can mitigate the volatility of renewable energy and improve the long-term operational efficiency of the grid. This study corresponds with the goals of Saudi Vision 2030 by supporting the diversification of energy sources, reducing reliance on fossil fuels, and increasing the contribution of clean energy to the national energy mix. Accordingly, the study recommends the following:

- Gradual expansion of solar and small modular nuclear power (SMR) projects.
- Investment in energy storage technologies and smart grids.
- Support for research and development programs in hybrid energy systems.
- Development of policies and regulations that encourage investment in green energy projects.

- Enhancing international cooperation in the fields of peaceful nuclear technology and renewable energy.

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