



IMPACT OF RENEWABLE ENERGY ON POTENTIAL GREEN COMMUNITIES - CASE STUDY: MADINATY, EGYPT

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ABSTRACT

The concept of sustainability has garnered widespread attention across the globe, as societies strive to address environmental, social, and economic challenges. Within this context, this paper delves into the paramount importance of harnessing green energy applications to foster sustainable development within Green Communities. These communities are purposefully designed to incorporate a range of strategies that prioritize environmentally friendly buildings, integrated water systems, pedestrian-friendly design, urban green spaces, and effective waste management practices. The study underscores the significance of meticulous planning at the neighborhood level in order to ensure long-term viability and minimize the environmental impact of sustainable communities. Key factors such as population density, alternative transportation systems, community-based agriculture programs, water reuse strategies, and innovative green building techniques are highlighted as crucial contributors to achieving sustainable development goals. Renewable energy plays a pivotal role in the advancement of green communities. The paper places particular emphasis on the seamless integration of renewable energy sources and the judicious selection of alternative fuels and electric vehicles to curtail greenhouse gas emissions, combat climate change, and mitigate air pollution. In conclusion, this manuscript underscores the profound significance of incorporating renewable energy applications into the planning and development of Green Communities. By doing so, we can foster a greener and more sustainable future.

KEYWORDS: Green communities, Renewable energy applications, Emissions

تطبيقات الطاقة المتجددة في المجتمعات الخضراء القادمة – دراسة حالة: مدينتي، مصر

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المخلص

لقد حظي مفهوم الاستدامة بتركيز واسع النطاق على مستوى العالم، حيث تسعى المجتمعات لمعالجة التحديات البيئية والاجتماعية والاقتصادية. في هذا السياق، يتعمق هذا البحث في الأهمية البارزة لاستغلال تطبيقات الطاقة الخضراء لتعزيز التنمية المستدامة داخل المجتمعات الخضراء. تم تصميم هذه المجتمعات بقصد دمج مجموعة من الاستراتيجيات التي تعطي الأولوية للمباني الصديقة للبيئة وأنظمة المياه المتكاملة وتصميم الأماكن العامة المناسبة للمشاة والمساحات الخضراء الحضرية وممارسات إدارة النفايات الفعالة. يؤكد البحث أهمية التخطيط الدقيق على مستوى الحي من أجل ضمان الاستدامة على المدى الطويل وتقليل الأثر البيئي للمجتمعات

المستدامة. يتم تسليط الضوء على عوامل رئيسية مثل كثافة السكان وأنظمة النقل البديلة وبرامج الزراعة القائمة على المجتمع واستراتيجيات إعادة استخدام المياه وتقنيات البناء الخضراء المبتكرة كمساهمين حاسمين في تحقيق أهداف التنمية المستدامة.

تلعب الطاقة المتجددة دورًا حاسمًا في تقدم المجتمعات الخضراء. يولي البحث تركيزًا خاصًا على التكامل السلس لمصادر الطاقة المتجددة والاختيار الحكيم للوقود البديل والمركبات الكهربائية للحد من انبعاثات غازات الاحتباس الحراري ومكافحة تغير المناخ والتخفيف من تلوث الهواء.

في الختام، يؤكد هذا المقال على أهمية عميقة لاستخدام تطبيقات الطاقة المتجددة في التخطيط والتطوير للمجتمعات الخضراء. من خلال ذلك، يمكننا تعزيز مستقبل أكثر خضرة ومستدامة.

الكلمات المفتاحية : المجتمعات الخضراء، تطبيقات الطاقة المتجددة، الانبعاثات

1. INTRODUCTION

Green communities are emerging as innovative models for sustainable development, prioritizing environmental stewardship, social well-being, and economic prosperity. These communities integrate renewable energy technologies to reduce their carbon footprint, enhance energy efficiency, and promote a cleaner and healthier living environment [1]. However, a research problem persists regarding the lack of confidence in the ability of renewable energy applications to meet energy needs. The objective of this study is to address this problem by exploring the diverse applications of renewable energy in potential green communities and investigating the feasibility, challenges, and benefits of implementing renewable energy solutions. By focusing on a case study of Madinaty, an Egyptian community with visionary urban planning and favorable solar resources, valuable insights can be gained to accelerate the transition towards a more sustainable and renewable energy-powered future.

Renewable energy sources, such as solar, wind, hydro, and biomass, have gained widespread recognition for their numerous benefits in green communities. First and foremost, renewable energy helps mitigate climate change by reducing greenhouse gas emissions [2]. By shifting away from fossil fuels, green communities can significantly contribute to global efforts in combating climate change and achieving carbon neutrality. Additionally, renewable energy technologies offer energy security and independence, as they rely on domestic resources that are replenishable, unlike finite fossil fuel reserves [3].

The integration of renewable energy in green communities brings about multiple direct and indirect benefits. One of the key advantages is improved air quality. By replacing conventional power generation methods with clean energy sources, such as solar panels or wind turbines, emissions of pollutants and particulate matter are significantly reduced, leading to cleaner and healthier air for residents. This, in turn, contributes to the overall well-being and health of the community [4]. However, the lack of confidence in the ability of renewable energy applications to meet energy needs hinders the realization of these benefits.

Furthermore, renewable energy promotes energy efficiency and cost savings [5]. Green communities often incorporate energy-efficient building designs, smart grid systems, and advanced technologies that optimize energy consumption. By combining these strategies with renewable energy generation, communities like Madinaty can reduce their energy demand, lower utility costs for residents, and create a more sustainable and affordable energy infrastructure [6]. The hypothesis of this study posits that the optimal use of various alternatives of renewable energy applications and the selection of appropriate technology can lead to enhancing and activating the role of different renewable energy

applications, effectively reducing costs, and decreasing the use of fossil fuels by a certain percentage, consequently reducing emissions by a certain percentage as well.

Madinaty, as a case study, holds particular significance due to its unique characteristics. Situated in Egypt, a country abundant in solar resources, Madinaty has immense potential for solar energy utilization. The region's high solar irradiance and extended periods of sunshine make it an ideal setting for solar power generation [7]. The integration of solar panels on rooftops and solar farms within the community can harness this abundant solar energy, providing a reliable and sustainable source of electricity. By examining the applications of renewable energy in Madinaty, this case study aims to provide valuable insights into the feasibility, challenges, and benefits of implementing renewable energy solutions in potential green communities.

The findings of this study can contribute to knowledge sharing, policy development, and the replication of successful models in similar contexts around the world. By addressing the research problem of the lack of confidence in the ability of renewable energy applications to meet energy needs, this study seeks to instill greater confidence in the potential of renewable energy to drive sustainable development. Ultimately, green communities that embrace renewable energy technologies offer a sustainable and resilient pathway for future urban development. Madinaty, with its visionary approach to urban planning and its favorable solar resources, provides a compelling case study for understanding the applications of renewable energy in potential green communities. Through this study, we can gain valuable lessons and insights to accelerate the transition towards a more sustainable and renewable energy-powered future.

2. Towards Creating Green Communities

Green communities are different from traditional communities in that they prioritize energy efficiency and sustainable building practices. They may include features such as solar panels, geothermal heating and cooling systems, and green roofs. In addition, green communities often have pedestrian-friendly designs with sidewalks, bike lanes, and public transportation options, as well as green spaces such as parks and community gardens. Living in a green community provides a wealth of benefits for residents, including improved health and well-being, increased morale, reduced energy costs, and a reduced impact on the environment [8].

2.1. Aspects of Green Communities

A green community promotes sustainability thereby it can create a healthy lifestyle to its citizens, thus can achieved through the following principles:

a) Public transportation:

Green communities prioritize the development and improvement of public transportation systems, such as buses, trams, trains, and subways. By providing convenient, accessible, and affordable public transportation options, these communities encourage residents to choose sustainable modes of transportation over private cars, reducing congestion and air pollution [9].

b) Walkable and bikeable neighborhoods:

Walkability and bikeability are essential characteristics of green communities. These communities are designed with pedestrian-friendly infrastructure, including well-maintained sidewalks, dedicated bike lanes, and interconnected pathways. By promoting walking and cycling as viable transportation options, green communities reduce reliance on cars, promote physical activity, and create vibrant, human-scale neighborhoods [9].

c) Renewable energy generation:

Green communities prioritize the use of renewable energy sources, such as solar, wind, geothermal, and hydroelectric power. They invest in renewable energy infrastructure and encourage the adoption of renewable energy technologies, such as solar panels and wind turbines. By generating clean and sustainable energy locally, green communities reduce greenhouse gas emissions and contribute to the global transition towards a low-carbon future [10].

d) Vehicle charging stations:

To support the adoption of electric vehicles (EVs), green communities provide ample vehicle charging stations throughout the community. These charging stations make it convenient for EV owners to charge their vehicles and encourage the transition from fossil fuel-powered cars to electric transportation, reducing air pollution and dependence on finite fossil fuel resources [9].

e) Green buildings:

Green communities prioritize the construction and retrofitting of buildings to be energy-efficient and environmentally friendly. Green buildings incorporate sustainable design principles, such as efficient insulation, energy-saving appliances, and renewable energy systems. They also focus on using environmentally friendly materials and implementing water-saving measures. Green buildings not only reduce energy consumption and carbon emissions but also provide healthier and more comfortable living and working spaces for residents [9].

f) Food production:

Green communities promote local and sustainable food production by integrating urban agriculture, community gardens, and rooftop gardens. These initiatives reduce the carbon footprint associated with food transportation, increase access to fresh and healthy produce, and foster community engagement and education around sustainable food practices [9].

g) Public green spaces:

Green communities prioritize the creation and preservation of public green spaces, such as parks, gardens, and green corridors. These spaces provide opportunities for recreation, relaxation, and connection with nature. Public green spaces improve air quality, support biodiversity, mitigate the urban heat island effect, and enhance the overall well-being of residents [9].

h) Waste management:

Green communities adopt comprehensive waste management strategies that prioritize waste reduction, recycling, and composting. They implement recycling programs, promote waste separation at the source, and explore innovative waste-to-energy technologies. By minimizing waste sent to landfills and promoting a circular economy, green communities reduce environmental impact and conserve resources [9].

i) Water conservation:

Green communities emphasize water conservation by implementing water-efficient practices and technologies. They promote water-saving fixtures, implement efficient irrigation systems, and educate residents on water-wise behaviors. Water conservation measures in green communities ensure the sustainable use of water resources, protect water quality, and reduce the strain on water infrastructure [9].

j) Water efficiency:

Green communities focus on maximizing water efficiency in various sectors, including residential, commercial, and industrial. They encourage water-efficient appliances, fixtures, and landscaping practices. By reducing water consumption, green communities contribute to water conservation efforts, alleviate pressure on water supplies, and promote long-term water sustainability [9].

By incorporating these characteristics, green communities strive to create sustainable and livable environments that promote environmental stewardship, social cohesion, and economic prosperity. These communities serve as models for sustainable development and inspire positive change in urban planning and design practices [11].

2.2 The Challenges of Future Green Communities

Despite the many benefits of green communities, such as improved environmental sustainability and enhanced quality of life, there are challenges involved in their creation. One significant challenge is the higher upfront costs associated with implementing sustainable building practices and infrastructure, see Fig.1. These costs can make it difficult to attract developers and investors who may prioritize short-term financial gains [12]. Additionally, there is a need for community engagement and buy-in, as residents may be resistant to changes in their neighborhood or skeptical of the benefits of sustainability. Overcoming these challenges requires proper planning, investment, and effective communication to ensure that residents understand the long-term advantages of sustainable development [12].

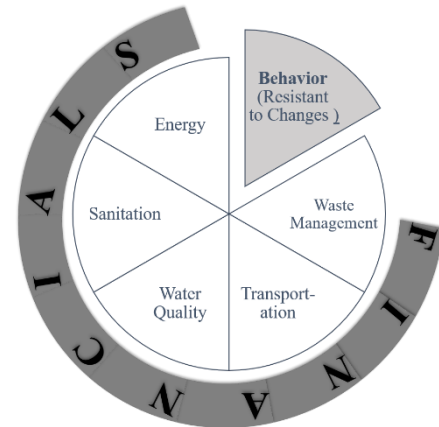


Fig.1. Financials and Non-Financial Challenges

However, as the world becomes increasingly urbanized and the effects of climate change continue to threaten our planet, the demand for sustainable communities will only grow. Green communities offer a promising solution to these challenges by providing a model for livable, environmentally friendly neighborhoods. These communities prioritize sustainability, energy efficiency, and the well-being of residents. They often incorporate features such as renewable energy sources, green spaces, efficient transportation systems, and sustainable waste management practices [13].

In the coming years, we can expect to witness a rise in the development of green communities worldwide. Governments, developers, and residents are increasingly recognizing the long-term benefits of sustainable urban development. By prioritizing sustainability and community well-being, we can create a brighter future for ourselves and future generations. It is crucial to continue investing in research, innovation, and collaboration to overcome the challenges and create thriving, sustainable communities that serve as models for urban development worldwide [13].

2.3 Successful previous experience of International Green Communities

As the world becomes increasingly urbanized and climate change continues to threaten our planet, the need for sustainable communities will only grow. Green communities offer a promising solution to these challenges, providing a model for livable, environmentally friendly neighborhoods. In the coming years, we can expect to see more green communities being developed around the world, as governments, developers, and residents recognize the benefits of sustainable urban development. By prioritizing sustainability and community well-being, we can create a brighter future for ourselves and future generations.

Green communities can be found all over the world, from urban centers to rural areas, such as:

- a) Masdar City in the United Arab Emirates (UAE):

Masdar City is a sustainable urban development located near Abu Dhabi, approximately 17 kilometers southeast of the city center. The planned area of Masdar City, **Fig.2.**, covers around 6 square kilometers. Currently, the population is relatively small, with around 2,000 residents, but the city is designed to accommodate up to 50,000 people when fully completed. The development of Masdar City was initiated in 2006 by the Abu Dhabi government, with a vision of creating a hub for clean technology and renewable energy. It aims to be a carbon-neutral development, primarily powered by renewable energy sources such as photovoltaic panels and concentrated solar power. The city also promotes sustainable transportation, with pedestrian-friendly design, extensive bicycle networks, and a Personal Rapid Transit (PRT) system using autonomous electric vehicles. Water conservation and recycling systems are implemented to minimize consumption, and sustainable buildings with energy-efficient designs and advanced cooling systems are incorporated throughout the city. Additionally, Masdar City is home to the Masdar Institute of Science and Technology, focusing on clean technology research and innovation [15].



Fig.2. Masdar City, U.A.E – Master Layout [14]

Water conservation and recycling systems are



Fig.3. Songdo International Business District, South Korea [16]

b) Songdo International Business District in South Korea:

Songdo International Business District is a vibrant urban center located in Incheon, South Korea. Situated on reclaimed land along the western coast, adjacent to Incheon International Airport, **Fig.3.**, the district spans an area of approximately 6 square kilometers. It is home to an estimated population of around 100,000 residents and offers a mix of residential, commercial, and cultural facilities. The planning and development of Songdo International Business District began in the early 2000s as a joint project between the South Korean government and private companies. The goal was to create a smart and sustainable city that would attract global businesses and residents. Many buildings in the district are certified under the Leadership in Energy and Environmental Design (LEED) rating system, ensuring high energy and environmental performance. One of the notable features is the expansive Central Park, offering recreational areas with walking paths, bike lanes, and water features. The district also employs an advanced waste management system using pneumatic waste collection, reducing reliance on traditional garbage trucks. With the integration of smart infrastructure, Songdo utilizes an extensive network of sensors and information technology to monitor and manage energy usage, traffic flow, and resource allocation. Moreover, the district incorporates extensive green spaces, parks, and landscaped areas to enhance air quality and provide natural environments within the urban setting [17].

c) Eco-City Tianjin in China:

Eco-City Tianjin is a sustainable urban development located in Tianjin, China. Tianjin itself is a major port city situated along the Bohai Sea in northeastern China, **Fig.4**. The Eco-City Tianjin project covers an area of around 31 square kilometers. Upon completion, the city is projected to have a population of 350,000 residents, and it is designed to feature a mix of residential, commercial, and industrial areas. Jointly developed by the governments of China and Singapore, the Eco-City Tianjin project was launched in 2008 as a model for sustainable urban development and cooperation between the two countries. Key green community features include low-carbon transportation options such as electric vehicles, bike-sharing programs, and pedestrian-friendly infrastructure. The city incorporates energy-efficient building designs, green building materials, and smart technologies to minimize energy consumption and reduce carbon emissions. Extensive green spaces, parks, and wetlands are featured in Eco-City Tianjin, contributing to improved air quality,



Fig.4. Eco-City Tianjin, China – Master Layout [18]

providing natural habitats, and managing stormwater runoff. The city also implements water-saving technologies like rainwater harvesting and wastewater treatment systems to minimize water consumption and promote water reuse. Additionally, Eco-City Tianjin utilizes a smart grid system to optimize energy distribution and consumption, integrating renewable energy sources and enabling efficient energy management [19,20].

3. Renewable Energy and Residential communities

3.1 Renewable Energy Background

Renewable energy is a type of energy that is derived from sources that are naturally replenished, such as sunlight, wind, water, and geothermal heat. Unlike fossil fuels, renewable energy sources are sustainable and have minimal impact on the environment. They offer the potential to reduce greenhouse gas emissions and decrease dependence on finite resources. The use of renewable energy is an important aspect of transitioning to a more sustainable and environmentally friendly energy system. It is also referred to as clean energy, as it comes from zero-emission sources that do not pollute the atmosphere when used. Renewable energy sources are virtually inexhaustible in duration, and they can help to diversify energy supply and reduce dependence on imported fuels. They also create economic development and jobs in manufacturing, installation, and more [21-23]. we can explore the types of renewable energy as follow:

- a) Solar Energy: Solar power converts sunlight directly into electricity using photovoltaic (PV) cells. It is utilized in applications ranging from small-scale electronics to large photovoltaic power plants, making a significant contribution to clean energy production [24,25].

- b) **Wind Energy:** Wind turbines capture the kinetic energy of wind to generate electricity. Wind power is cost-effective, has minimal environmental impact, and provides community benefits, making it a key component of renewable energy portfolios [26,27].
- c) **Hydroelectric Energy:** Hydropower plants harness the natural flow of water to generate electricity. The energy production depends on variations in water flow and elevation. Hydroelectricity is a major source of renewable electricity, particularly in regions with abundant water resources [28].
- d) **Geothermal Energy:** Geothermal energy taps into the Earth's heat, providing a reliable and low-emission energy source for heating, electricity generation, and other applications. It contributes to environmental sustainability and energy diversification [29].
- e) **Hydrogen Energy:** Hydrogen is a versatile and clean energy carrier, produced from various sources, including renewable energy. It has potential applications in transportation, power generation, and energy storage, facilitating the integration of renewables into existing infrastructure [30].
- f) **Biomass Energy:** Biomass involves using organic materials like wood, crops, and waste for energy production through combustion, biofuel conversion, or biochemical processes. It offers a sustainable alternative to fossil fuels and provides environmental benefits [31].
- g) **Ocean Energy:** Ocean waves represent a vast and largely untapped renewable energy resource with high power density. They have significant potential to reduce dependence on fossil fuels and contribute to sustainable global energy needs [32].

Each renewable energy source plays a crucial role in diversifying energy supply, reducing carbon emissions, and building a more sustainable future. By harnessing these abundant and inexhaustible resources, societies can mitigate climate change, enhance energy security, and promote economic prosperity.

3.2 Advantage and Disadvantage of Renewable Energy

3.2.1. Advantages of Renewable Energy:

- **Endless Supply:** One of the significant advantages of renewable energy is that it won't run out. Unlike fossil fuels, which are finite resources, renewable energy sources such as solar, wind, and hydroelectric power rely on natural processes that replenish themselves over time.
- **Lower Maintenance Requirements:** Renewable energy systems generally have lower maintenance requirements compared to traditional energy sources. Once installed, solar panels and wind turbines, for example, require minimal upkeep, reducing the need for frequent repairs and maintenance.
- **Cost Savings:** Utilizing renewable energy can lead to significant cost savings in the long run. While there may be higher upfront costs for installing renewable energy systems, the operational costs are often lower, as the fuel source is free and abundant. This can result in reduced energy bills for consumers and businesses alike.
- **Environmental Benefits:** Renewable energy sources offer numerous environmental benefits. They produce little to no greenhouse gas emissions during operation, helping to mitigate climate change. Additionally, they have a lower impact on air and water pollution compared to fossil fuel-based energy sources, leading to cleaner air and water quality.
- **Energy Independence:** By relying on renewable energy, countries can reduce their dependence on foreign energy sources. This helps enhance energy security, as renewable

resources are typically available domestically, reducing the need for reliance on imports and potential geopolitical risks associated with traditional fuel sources.

- **Improved Water and Air Quality:** The use of renewable energy can contribute to cleaner water and air. Unlike fossil fuel power plants, which release pollutants into the atmosphere and contribute to air pollution and acid rain, renewable energy systems produce little to no harmful emissions, leading to improved air quality. Moreover, renewable energy sources have minimal impact on water resources, reducing water pollution risks associated with traditional energy production methods.
- **Job Creation:** The renewable energy sector has the potential to create numerous job opportunities. From manufacturing and installation to maintenance and research, the development and expansion of renewable energy systems contribute to employment growth and the development of a skilled workforce.
- **Waste Reduction:** Renewable energy technologies often generate less waste compared to traditional energy sources. For instance, solar panels have a long lifespan and can be recycled at the end of their useful life, reducing waste accumulation and environmental impact [33,34].

3.2.2. Disadvantages of Renewable Energy:

- **High Upfront Costs:** One of the main drawbacks of renewable energy is the initial investment required for infrastructure setup. The cost of installing solar panels, wind turbines, or hydroelectric facilities can be relatively high, making it challenging for some individuals or organizations to afford.
- **Intermittency:** Unlike fossil fuels that provide a continuous and consistent energy supply, renewable energy sources can be intermittent. Solar power generation depends on sunlight availability, while wind power relies on wind speeds. This intermittency can pose challenges in meeting energy demands during periods of low resource availability.
- **Storage Limitations:** Storage capabilities for renewable energy are still developing. Storing large amounts of energy generated from renewable sources can be challenging and costly. Improvements in energy storage technologies are crucial for ensuring a stable and reliable energy supply from renewable sources.
- **Geographic Limitations:** Certain renewable energy sources, such as solar and wind, have geographic limitations. Solar power generation is most effective in regions with abundant sunlight, while wind power requires consistent wind patterns. This can restrict the widespread adoption of certain renewable energy technologies in areas with less favorable natural conditions.
- **Carbon Footprint:** While renewable energy sources are generally cleaner than fossil fuels, some renewable technologies may still have associated carbon emissions. For example, biomass energy can release carbon dioxide when organic materials are burned. However, these emissions are often considered carbon-neutral since the carbon released is part of the natural carbon cycle [33,34].

4. Case study of Potential Local Green Community in Egypt

4.1 Case study Selection of Madinaty city

Madinaty, a city of international standards, spans an expansive area of 33.6 million square meters in the northeast of New Cairo. Designed as a modern extension of New Cairo, it boasts a wide range of residential buildings, including villas and apartments, **Fig.5.**, catering to a total of 950,000 residents

across 120,000 residential units. The city offers a comprehensive array of amenities and facilities, such as an open-air mall that sprawls over 159 feddans, golf retreats, educational institutions, healthcare facilities, hotels, sports and social clubs, and entertainment destinations. In addition to serving its own residents, Madinaty is also set to provide unique services along its outskirts, catering to the needs of neighboring residential communities. These services include water sports facilities, shopping centers, and educational institutions, further enhancing the livability and convenience of the area [35].

4.2 Analysis of Madinaty city

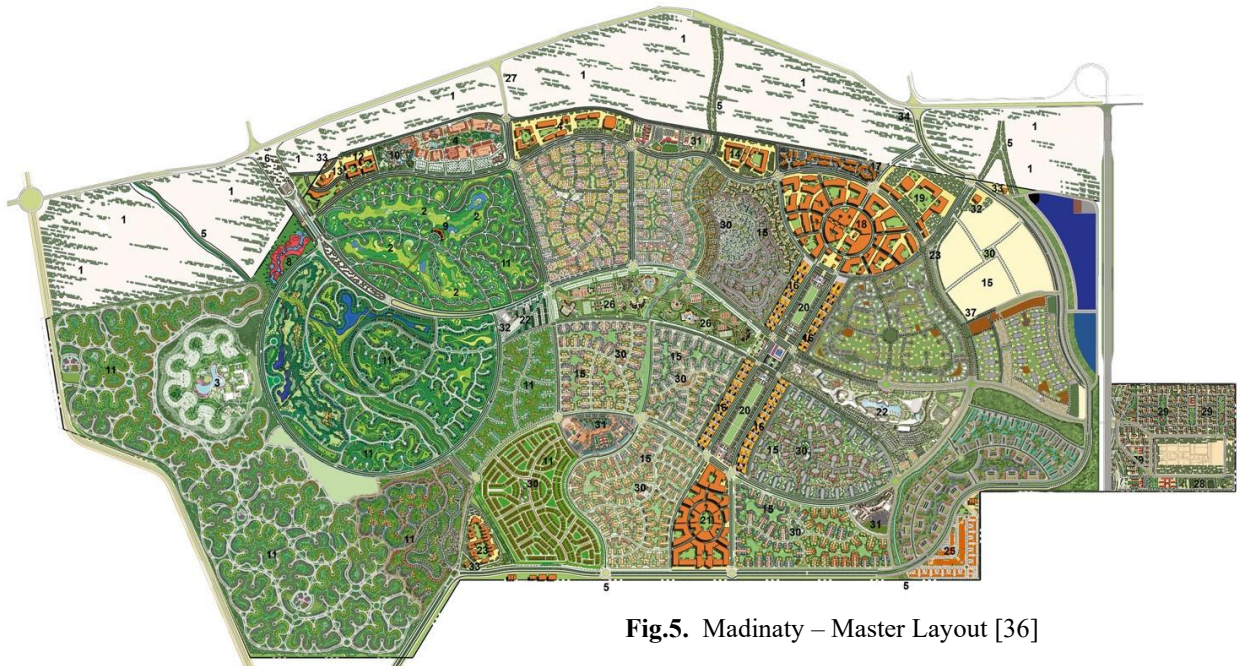


Fig.5. Madinaty – Master Layout [36]

The city's infrastructure includes an extensive network of utilities:

- a) **Water Network:** This comprises 7.041 km of ductile iron pipelines ranging from 300 mm to 900 mm in diameter, as well as 120.8 km of uPVC pipelines ranging from 90 mm to 225 mm in diameter. The network includes associated chambers, structures, and 700 house connections spanning a total length of 160.081 km.
- b) **Irrigation Network:** The irrigation network consists of 9.8 km of ductile iron pipelines ranging from 300 mm to 600 mm in diameter and 134 km of uPVC pipelines ranging from 40 mm to 315 mm in diameter.
- c) **Sewage Network:** Madinaty features an 89.136 km sewage network comprising ductile iron pipelines ranging from 200 mm to 600 mm in diameter, along with associated structures. Additionally, the city has 73 km of house connections.
- d) **Stormwater Network:** The stormwater network spans 90 km and includes ductile iron pipelines ranging from 160 mm to 700 mm in diameter.
- e) **Road Network:** Madinaty boasts a comprehensive road network covering a length of 100 km, with road widths ranging from 9 m to 22.8 m. The city also provides parking facilities spanning a total area of 510,000 m².
- f) **Low-Voltage Network:** The low-voltage network features 1,202 main distribution boards, 4,462 distribution boxes, and aluminum-armored cables with a total length exceeding 618 km.

- g) **Medium-Voltage Network:** Madinaty incorporates 8 medium-voltage distributors, 305 transformer kiosks, 317 earth pits, and aluminum-armored cables with a total length of about 171 km.
- h) **Telephone Network:** The city's telephone network consists of 2,187 telecom handholes and telecom wiring conduits with a total length exceeding 389 km.
- i) **Street Lighting:** Madinaty ensures well-illuminated streets with its 5,624 light poles, ranging from 5, 8, and 12 meters in height. The street lighting system includes associated lighting switches and aluminum-armored cables with a total length of about 225 km.

Through meticulous planning and execution, Madinaty has established itself as a thriving city that prioritizes modern living, convenience, and essential infrastructure to meet the needs of its residents and the surrounding communities [35-37].

5. Development of Renewable Energy Integration into Residential Communities

5.1 Determining the Integration of Renewable Energy in Residential Compound Electricity Networks

When choosing suitable renewable energy applications for a residential compound, there are several criteria to consider, and it's helpful to utilize the U.S. Department of Energy's (DOE) consumer resource on saving energy and using renewable energy technologies at home. Here are some key factors to take into account:

1. **Energy Needs:** Begin by assessing the energy needs of the residential compound. Evaluate the average electricity consumption, heating requirements, and hot water demand. This analysis will help determine the size and type of renewable energy systems required [38,39].
2. **Resource Availability:** Consider the renewable energy resources available in the area. Different locations have varying potential for solar energy, wind power, geothermal energy, biomass, or hydropower. Assess the feasibility and suitability of each resource based on the specific geographic and climatic conditions of the residential compound [38].
3. **Space Availability:** Evaluate the available space within the residential compound for installing renewable energy systems. Solar panels, wind turbines, or geothermal heat pumps may require a certain amount of area or specific infrastructure. Consider the roof space, backyard, or any other suitable locations for the installation [39].
4. **Local Regulations:** Familiarize yourself with local regulations and permits related to renewable energy installations. Some regions have specific guidelines or restrictions on the type, size, and location of renewable energy systems in residential areas. Ensure compliance with these regulations before finalizing any plans [39,40].
5. **Cost and Financial Viability:** Assess the upfront costs, maintenance expenses, and potential savings associated with renewable energy systems. Calculate the payback period and return on investment (ROI) to determine the financial viability of different options. Consider available incentives, tax credits, or financing options that may help reduce the initial investment [38].
6. **System Integration:** Analyze the compatibility and integration of renewable energy systems with the existing infrastructure of the residential compound. Determine how the renewable energy system will interact with the electrical grid, heating systems, or other energy-related components. Ensure that the integration is technically feasible and cost-effective.
7. **Environmental Impact:** Evaluate the environmental benefits and impacts of each renewable energy option. Consider factors such as carbon footprint, air pollution, water usage, and waste

generation associated with the chosen technology. Opt for renewable energy systems that have a minimal environmental impact [38].

8. **Maintenance and Support:** Investigate the maintenance requirements and availability of technical support for different renewable energy systems. Ensure that the chosen technology is reliable, and there are trained professionals available for installation, monitoring, and maintenance [40].

By considering these criteria holistically, you can identify suitable renewable energy applications that align with the specific needs and constraints of the residential compound while promoting sustainability and energy efficiency.

5.2 Identifying Suitable Sectors for Replacement with Renewable Energy

The following sectors are considered the most suitable for using renewable energy applications based on the data studied: electricity demand for continuous, reliable supply that has traditionally been provided by base-load electricity generation, shorter-term (e.g. peak-load) requirements on a broadly predictable daily and weekly basis, and stand-alone systems. Renewable energy sources such as wind and solar are readily available and in most cases cheaper than coal, oil, or gas [41-43]. Policies that favor renewables over other sources may also be required, such as priority dispatch for electricity from renewable sources and special feed-in tariffs, quota obligations, and energy tax exemptions [41]:

1. **Street Lights:** Solar-powered Street lights are a popular choice for residential compounds. These lights consist of solar panels that capture sunlight during the day and convert it into electricity, which is stored in batteries. The stored energy is then used to power the street lights during the night. Solar street lights are independent of the electrical grid, making them a reliable and sustainable lighting solution.
2. **Landscape Lighting:** Solar-powered lighting systems can also be used for landscape lighting within residential compounds. These systems operate similarly to solar street lights, with solar panels collecting energy during the day to power the landscape lights at night. They are easy to install and require minimal maintenance, making them a practical choice for illuminating gardens, pathways, and other outdoor areas [44].
3. **Irrigation Systems:** Renewable energy can be used to power irrigation systems in residential compound landscapes. Solar-powered pumps can be employed to draw water from wells or other water sources and distribute it for irrigation purposes. These pumps are driven by solar energy, eliminating the need for grid electricity and reducing operational costs. Additionally, water management systems can be designed to utilize rainwater harvesting, which is a sustainable approach to irrigation [45,46].

By integrating renewable energy solutions for street lights, landscape lighting, and irrigation systems, residential compounds can reduce their dependence on conventional energy sources and minimize their carbon footprint. These applications not only promote energy efficiency but also contribute to the overall sustainability and aesthetics of the compound.

5.3 Possibility of Renewable Energy Application in Madinaty

When examining the master plan of Madinaty and the vast green spaces it encompasses, the potential for generating clean, renewable energy to serve the community and reduce dependence on non-renewable energy sources becomes apparent. The challenge is identifying the most appropriate ways to exploit these resources effectively. By exploring the potential green energy applications for residential green communities, such as Madinaty, we can promote a more sustainable and

environmentally friendly energy system, reducing carbon emissions and promoting a cleaner and healthier planet. From the statistics highlighted in the previous section, it is evident that there is a significant potential for harnessing renewable energy in Madinaty, particularly through the utilization of rooftops and available land. The roofs of buildings in Madinaty have a substantial total surface area, estimated to be around 3.15 km² which presents an excellent opportunity for installing solar cells and generating solar energy.

Furthermore, by reviewing the topographic map of the land, as shown in Fig.6 and the wind rose direction, as shown in Fig.7, and comparing it with the master plan, it becomes apparent that the plots

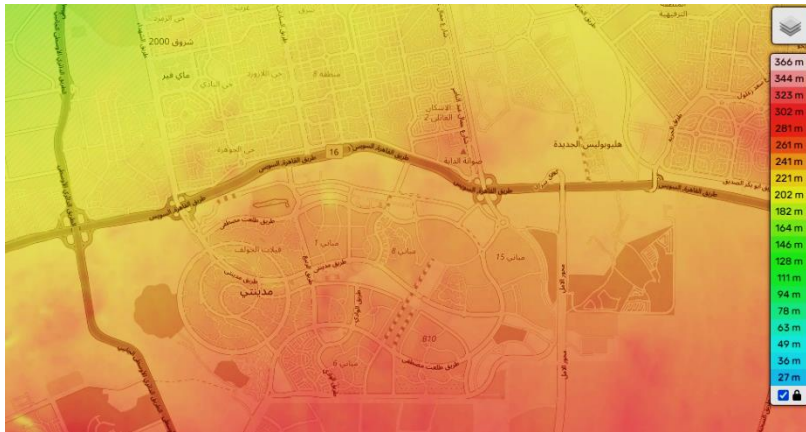


Fig.6. Madinaty Topographical Map [47]

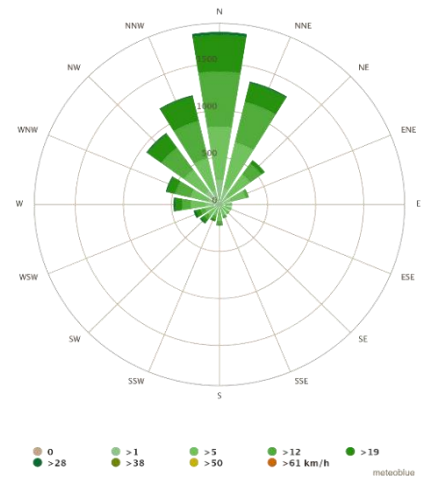


Fig.7. Cairo Gov. Wind Rose Direction [48]

used in the landscape, particularly those along the Suez Road, have a favorable orientation towards the north and northeast. Not only that, but the elevation of these areas is higher than the opposite part of Suez Road. This evidence makes this area suitable for installing windmills or wind turbines, which can harness wind energy and generate significant quantities of power.

By maximizing the use of rooftops for solar energy generation and utilizing the available land for wind energy production, Madinaty can tap into multiple renewable energy sources. This integrated approach can diversify the energy portfolio of the community and enhance its energy self-sufficiency. Moreover, it aligns to reduce operational costs and minimize emissions by decreasing reliance on fossil fuels.

Therefore, this paper specifically focuses on the implementation and benefits of using PV systems on rooftops as one of the prominent renewable energy applications. By strategically deploying solar cells on rooftops and complementing them with wind turbines in suitable locations, Madinaty can effectively harness solar power and tap into the full potential of renewable energy sources. This approach will not only contribute to a cleaner and more sustainable energy future but also optimize the use of available resources within the community.

The performance of a Solar PV system is intricately tied to a set of key parameters [49], which determine its effectiveness and efficiency. These parameters can be categorized into two main groups: those influenced by the design and equipment selection, and those influenced by the site and environmental conditions. Understanding and optimizing these parameters is crucial for maximizing the performance of Solar PV Plants. Below, the study has outlined some of the key parameters that have a direct or indirect impact on the performance of Solar PV systems:

- a) Site and Environmental Conditions:
- **Solar Irradiance:** The amount of solar radiation received at the site affects the energy generation potential of the solar panels. Regions with higher solar irradiance generally yield greater energy output. Figure 7 shows the solar radiation overall the country and the potential photovoltaic locations [49,50].
 - **Shading:** The presence of shading, such as from nearby buildings, trees, or other obstructions, can reduce the amount of sunlight reaching the solar panels, impacting their performance [49].
 - **Temperature:** Solar panels are sensitive to temperature variations. Higher temperatures can decrease panel efficiency, so proper cooling and ventilation mechanisms are important for optimal performance [50].
 - **Dust and Pollution:** Accumulation of dust, dirt, or pollutants on the surface of solar panels can reduce their ability to absorb sunlight, leading to decreased energy production. Regular cleaning and maintenance are essential [49].
 - **Geographical Location:** Factors like latitude, longitude, and local climate conditions influence the solar energy potential and should be considered during system design and planning [50].
- b) Design and Equipment Selection:
- **Solar Panel Efficiency:** The efficiency of the solar panels themselves plays a vital role in determining the overall system performance. Higher panel efficiency translates to a greater conversion of sunlight into electricity [51].
 - **Inverter Efficiency:** The efficiency of the inverter, which converts the direct current (DC) produced by the solar panels into usable alternating current (AC), affects the overall system efficiency [51].
 - **Wiring and Connections:** Proper wiring and connections are essential to minimize power losses and ensure optimal energy transfer within the system [51].
 - **Mounting and Tracking Systems:** The design and quality of the mounting and tracking systems impact the positioning and orientation of the solar panels, optimizing their exposure to sunlight throughout the day [51].
 - **Component Quality:** The quality and reliability of the components used in the system, including panels, inverters, wiring, and mounting systems, can significantly influence the system's performance and longevity [51].

5.4 Achieving Optimal Energy Conservation and Carbon Footprint Reduction through Strategic Renewable Energy Integration

In this study, our primary focus will be on harnessing the untapped potential of rooftops in prominent facilities, particularly residential buildings. These buildings encompass roughly 10% of the overall gross area, amounting to an impressive 3.15 square kilometers. To arrive at a more accurate estimate, we can exclude public use and shared spaces, which make up approximately 25% of the total area. Consequently, we can deduce that we have approximately 2.4 square kilometers of rooftop space that holds immense potential for energy generation through the implementation of photovoltaic (PV) systems. According to Great Plains Institute's (GPI) and Solar Energy Industries Association (SEIA), A conservative estimate suggests that solar development typically requires approximately 10 acres (equivalent to 0.04 square kilometers) of land to generate one megawatt (MW) of electricity. This estimation takes into account the necessary site development around the solar arrays, including provisions for maintenance and convenient site access [52,53]. Based on this estimate, we can deduce

that the available rooftop spaces mentioned can accommodate and potentially produce around 60 MW of electricity through the implementation of photovoltaic (PV) systems.

Based on the provided statistics, it is evident that Madinaty is equipped with an extensive network of 5,624 light poles for street lighting purposes. Each of these light poles consumes approximately 200 watts of power [54]. By multiplying the power consumption per pole (200W) by the total number of light poles (5,624), it can be estimated that the street lighting infrastructure in Madinaty requires around 1.2 megawatts of electricity to operate efficiently. This substantial power demand emphasizes the importance of exploring energy-efficient solutions and sustainable alternatives to reduce energy consumption and promote environmental sustainability in the compound [55].

Moreover, within the compound, there exists a vast expanse of 12.78 km² of landscape area. Accommodating such extensive green spaces, including sprawling golf courses, necessitates a substantial amount of water and the implementation of large-scale irrigation systems. To ensure efficient irrigation coverage throughout the compound, a network of distribution channels is required, enabling water to reach every corner of the landscape. Powering these irrigation pumps demands a significant electrical capacity, estimated to be nearly 2,000 kilowatts (KW). Such a high-power requirement underscores the scale and complexity of the irrigation infrastructure needed to maintain the vibrant greenery and lush vegetation that embellish the compound [56].

Therefore, after the completion of constructing the compound zones, the maximum full energy produced by PV systems and from here, calculating carbon emissions from electricity usage involves a comprehensive understanding of two key factors: the amount of electricity consumed and the carbon intensity of the electricity source. To calculate these emissions, the next outlined steps could be followed:

- Electricity consumption: Determine the daily and yearly electricity usage in kilowatt-hours (kWh).
- Carbon intensity of the main electricity source: The carbon intensity is measured in grams of CO₂ emitted per kilowatt-hour (kWh) of electricity generated. This value varies depending on the energy mix in the region, which can include sources like coal, natural gas, or renewables. The following table 1 provides the carbon intensities associated with each power source [57].

Table 1. indicates the approximate carbon intensity factors for different energy sources:

Table.1. Carbon Intensity Factor (CO₂/kWh) [58]

Energy Source	Carbon Intensity Factor (CO₂/kWh)
Coal	0.9 - 1.1 kg CO ₂ /kWh
Natural Gas	0.4 - 0.6 kg CO ₂ /kWh
Oil	0.7 - 0.9 kg CO ₂ /kWh
Nuclear	0.01 - 0.05 kg CO ₂ /kWh
Hydroelectric	0 g CO ₂ /kWh (negligible)
Solar	0 g CO ₂ /kWh (negligible)
Wind	0 g CO ₂ /kWh (negligible)

- Calculate daily emissions: Multiply the daily electricity consumption (in kWh) by the carbon intensity of the electricity source (in grams of CO₂ per kWh). This calculation will yield the amount of CO₂ emissions resulting from daily electricity usage [58].
- Daily emissions (grams of CO₂) = Daily electricity consumption (kWh) × Carbon intensity (grams of CO₂ per kWh).

By applying the given figures, the emissions can be prevented by utilizing renewable energy applications instead of fossil fuel-produced energy will be as follows:

- *Daily emissions (grams of CO₂) = 60,000 (kWh) × 0.5 (g of CO₂ per kWh) = 30,000 g/kWh*
- *That is equals 30 kg of CO₂ per day*
- *To calculate the annual conservation value = 30 kg of CO₂/day × 365 = 10,950 kg of CO₂ per annum.*

To summarize, the utilization of renewable energy applications instead of fossil fuel-produced energy presents a compelling opportunity to achieve substantial emissions reductions. These calculations underscore the transformative potential of adopting renewable energy technologies, underscoring the urgency of transitioning towards sustainable energy sources to combat climate change and curtail greenhouse gas emissions. By wholeheartedly embracing renewable energy solutions, we can actively contribute to the creation of a greener and more sustainable future, leaving a positive legacy for generations to come.

Conclusions

From the apparent results, it is clear that the consumption of street lighting and public facilities, in addition to irrigation systems for green areas, does not consume a large amount of the energy produced by solar energy systems. This observation indicates that there is potential to maximize the utilization of surplus energy produced by solar systems and expand its scope to supply other applications with energy. By tapping into this surplus energy, we can further reduce our reliance on traditional energy sources and contribute to a more sustainable energy ecosystem. Additionally, the efficient utilization of surplus solar energy can help address the intermittency challenge often associated with renewable energy sources, ensuring that energy generated during peak sunlight hours is efficiently utilized and increasing the overall efficiency and reliability of solar energy systems.

Expanding the scope of surplus energy utilization offers economic benefits by harnessing excess energy to power various applications, leading to cost savings for individuals and communities. This surplus energy can be directed towards charging electric vehicles, powering residential appliances, or supplying energy to nearby commercial establishments, reducing reliance on traditional grid electricity and lowering energy costs for consumers. Implementing these solar-powered applications on a larger scale in residential areas and communities will result in reduced reliance on fossil fuel sources, decreasing continuous consumption and payments associated with traditional energy sources.

Moreover, the widespread adoption of solar-powered applications will contribute to a significant reduction in carbon emissions, replacing fossil fuel-based energy systems with clean and renewable solar energy. This transition aligns with global efforts to combat climate change and promote a sustainable future. It not only reduces greenhouse gas emissions but also addresses environmental impacts. Additionally, the deployment of solar-powered applications can stimulate local economies and create job opportunities in the renewable energy sector, generating employment through the installation, maintenance, and operation of solar energy systems. Furthermore, reduced reliance on

fossil fuel imports enhances energy security and improves the balance of trade for countries heavily dependent on imported energy resources.

In conclusion, the efficient utilization of surplus solar energy and the widespread adoption of solar-powered applications hold great potential for maximizing energy efficiency, reducing carbon emissions, and promoting economic growth. By leveraging surplus energy to power various applications, we can contribute to a more sustainable and resilient energy future.

Recommendations

It is recommended to share the results with government agencies to leverage their influence in developing laws and legislation that promote the gradual adoption of renewable energy applications in residential communities. By establishing supportive policies and regulations, governments can create an enabling environment for the widespread implementation of solar-powered applications. These measures can include setting incentives for citizens and real estate developers to adopt renewable energy technologies, such as tax credits, grants, or subsidies. Additionally, governments can play a crucial role in promoting the development and integration of renewable energy into the national energy system. This aligns with the country's commitment to achieving its renewable energy targets, such as the goal of achieving 42% renewable electricity generation by 2030, as stated in the Nationally Determined Contribution (NDC).

moreover, research should be conducted to explore the feasibility of expanding the use of renewable energy sources effectively in various high-energy consumption applications, such as air conditioning systems, water pumps, and other non-core systems. Investigating the potential of renewable energy technologies to power these applications can provide valuable insights into their scalability and effectiveness. This research can help identify any technological or infrastructure limitations that may exist and inform strategies for overcoming them. By understanding the capabilities and limitations of renewable energy sources in different applications, researchers can contribute to the development of innovative solutions and advancements in renewable energy technology.

Further, it is crucial for researchers to actively contribute and conduct further studies aimed at expanding the effective utilization of wind turbines as a prominent source of renewable energy. As discussed in article (5.3), these research efforts should focus on understanding the specific ways to optimize wind turbine deployment based on the land's topography and identifying innovative solutions that can drive progress in renewable energy technology. By undertaking such research endeavors, we can unlock the full potential of wind energy and pave the way for its widespread adoption in a manner that aligns with the characteristics of the land and promotes sustainable development.

Collaboration between researchers, industry stakeholders, and policymakers is essential to drive the adoption of renewable energy applications in high-energy consumption systems. By fostering partnerships, sharing knowledge, and facilitating dialogue, these stakeholders can collectively work towards identifying opportunities and addressing challenges in utilizing renewable energy sources effectively. Such collaboration can lead to the development of practical solutions, innovative business models, and supportive policies that enable the widespread integration of renewable energy into various applications.

It is important to prioritize education and awareness programs to inform and educate the general public about the benefits and potential of renewable energy applications. By raising awareness and promoting understanding of renewable energy technologies, individuals and communities can make informed

decisions about adopting these applications in their homes and businesses. Educational initiatives can include workshops, seminars, and campaigns that provide information on the advantages of renewable energy, its affordability, and its positive impact on the environment.

Financial institutions and investors should be encouraged to support renewable energy projects and applications. By providing access to financing options and investment opportunities, the financial sector can play a significant role in accelerating the adoption of renewable energy technologies. This can include offering favorable loan terms, creating dedicated funds for renewable energy projects, or incorporating renewable energy criteria into investment portfolios. Encouraging financial institutions to prioritize renewable energy investments can attract capital and spur further development in the sector.

By sharing the results with government agencies, conducting further research, fostering collaboration, prioritizing education and awareness, and engaging the financial sector, we can promote the widespread adoption of renewable energy applications in various systems with high energy consumption. These initiatives will contribute to achieving national renewable energy targets, reducing greenhouse gas emissions, and advancing toward a sustainable and resilient energy future.

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