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The role of renewable and cleaner energy in achieving sustainable development goals and enhancing nutritional outcomes: Addressing malnutrition, food security, and dietary quality

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Abstract

This paper explores how renewable energy plays a role in achieving Sustainable Development Goals (SDGs) and improving nutritional outcomes. Sources of energy like solar, wind and bioenergy can revolutionize food systems by enhancing aspects of food production, processing, storage and distribution to ensure a consistent and diverse food supply. The incorporation of energy in agriculture has demonstrated advantages, such as a 30% decrease in post-harvest losses through solar drying and a 15% boost in crop yields from solar powered irrigation in Bangladesh. These enhancements directly contribute to food availability and quality. Furthermore, the adoption of energy solutions has led to improved choices, exemplified by a 25% increase in milk consumption in rural Kenya thanks to solar refrigeration units. Renewable energy also promotes food security by supporting productivity in regions like sub–Saharan Africa and India while lowering malnutrition rates. The paper underscores the importance of policies, global partnerships and investments in research to enhance the efficiency and affordability of energy. Future studies should concentrate on assessments to gauge the lasting effects of energy on food security and nutrition while exploring emerging technologies such as advanced bioenergy and microgrid systems. The integration of energy into food systems presents a path, towards sustainable development and enhanced nutritional outcomes.

Keywords: Renewable Energy; Food Security; Solar Irrigation; Nutritional Outcomes; Sustainable Development Goals (SDGs)

1. Introduction

1.1. Background on the Importance of Renewable and Cleaner Energy

Renewable and cleaner energy sources are now essential in dealing with the challenges posed by climate change environmental degradation and sustainable development. As fossil fuels continue to be a contributor to greenhouse gas emissions the transition to renewable energy sources like solar, wind, hydro and biomass is crucial. Data from the International Energy Agency (IEA) shows that renewable energy sources made up 28% of electricity generation in 2020 with this percentage expected to increase significantly as countries embrace greener energy initiatives (Yoshikawa and Anbumozhi 2022). This shift is not just vital for sustainability. Also offers economic and social advantages such as creating jobs enhancing energy security and improving public health (Idoko et, al., 2024).

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The environmental advantages of energy are significant. For example, solar and wind power produce emissions during operation compared to coal or natural gas plants which release quantities of CO2. According to estimates by the U.S. Environmental Protection Agency (EPA) each megawatt hour (MWh) of electricity generated from renewables can cut down CO2 emissions by 0.5 to 1 ton depending on the type of fossil fuel being replaced (Young et al., 2022). Moreover, renewable energy technologies often require water for cooling purposes than traditional power plants do helping address another resource limitation, in various regions.

The economic advantages are also quite significant. The renewable energy industry has played a role in creating jobs. In 2019 than 11 million individuals were employed globally in the energy sector with solar photovoltaic (PV) technology accounting for roughly one third of these positions (Mengi Dinçer et al., 2021). Countries like China, the United States (US) and Germany have experienced job growth in the industry underscoring the potential for economic rejuvenation through investments in green energy.

Looking at it from a standpoint, renewable energy helps enhance energy security by broadening the energy sources and decreasing reliance on imported fuels. This is especially advantageous for developing nations that frequently encounter fluctuating fossil fuel prices and disruptions in supply. Renewable energy systems, decentralized options such as home systems and mini grids offer consistent access to electricity, in remote regions improving living standards and creating economic opportunities (Zhang, 2022).

1.2. Overview of Sustainable Development Goals (SDGs) Related to Energy and Nutrition

The United Nations SDGs established in 2015 offer a framework for development initiatives until 2030. Among the 17 objectives a number directly addresses energy and nutrition illustrating the interconnected nature of development.

SDG 7 known as Clean Energy strives to guarantee access to reliable sustainable and modern energy for all. Achieving this target entails expanding infrastructure and upgrading technology to deliver energy across all regions worldwide. As of 2019 around 789 million individuals still lacked electricity access in Saharan Africa and South Asia highlighting the pressing need for action (IEA, 2021). The transition to renewable energy plays a role in meeting the goals of SDG 7; efforts such as the International Solar Alliance and various national renewable energy objectives are propelling advancements (Krannich, and Reiser, 2021).

The availability of energy is closely intertwined with SDGs. For example, SDG 2 focuses on Zero Hunger by stressing food security and enhanced nutrition. Renewable energy can support food security by powering activities, like irrigation systems, processing facilities and storage units. This can help reduce harvest losses and enhance food availability.

A recent report, from the FAO pointed out that using energy for irrigation could greatly enhance productivity and incomes in rural areas (FAO, 2021). When it comes to achieving SDG 3 (Good Health and Well-being) energy also plays a role. Clean energy helps reduce air pollution a health hazard identified by the World Health Organization (WHO) as responsible for around 7 million deaths annually (WHO, 2023). Shifting to energy sources can help address health problems linked to the burning of fuels, such as respiratory illnesses and heart conditions.

SDG 13 (Climate Action) underscores the need to tackle climate change and its effects. Renewable energy is instrumental in cutting down greenhouse gas emissions thereby mitigating climate change. The Intergovernmental Panel on Climate Change (IPCC) has stressed that swift adoption of energy is crucial to limit global temperature rise to, below 2°C as outlined in the Paris Agreement (Allen, 2018).

1.3. Purpose and Scope of the Review

The aim of this evaluation is to investigate the impact of cleaner energy, on achieving the Development Goals (SDGs) particularly in improving nutritional outcomes combating malnutrition ensuring food security and enhancing dietary quality. This assessment seeks to connect the dots between energy and nutrition by exploring how renewable energy projects contribute to results and overall well-being. While the interconnectedness of energy with development aspects has been recognized there is a call for an examination that sheds light on the specific pathways through which renewable energy influences nutrition and food security.

This assessment offers an exploration of energy technologies and their current global standing emphasizing advancements and trends in their adoption. By focusing on technologies like solar, wind, hydro and biomass energy this assessment will underscore how these innovations play a role in development and improved nutritional outcomes. Additionally, it delves into policy frameworks and international partnerships that promote the growth of energy projects by showcasing initiatives and exemplary practices.

Moreover, this evaluation investigates how renewable energy mechanisms impact outcomes by looking at its role, in boosting food production, processing, storage and distribution - all components of ensuring food security.

Through examining real world data and examples the review seeks to offer an insight into how renewable energy initiatives have tackled malnutrition issues and enhanced the nutritional value of diets in different areas.

1.4. Structure of the paper

The document is structured into sections. It starts with the Introduction, which discusses the background and significance of cleaner energy in tackling challenges and promoting sustainable development. Following that Section 2 Renewable and Cleaner Energy Initiatives explores the definitions, categories and current worldwide status of energy sources while presenting project case studies. Section 3 Sustainable Development Goals and Energy delves into the SDGs linked to energy. Emphasizes the crucial role of renewable energy, in achieving these goals through policy frameworks and international partnerships. Section 4 Disaster Management Strategies talks about how renewable energy contributes to enhancing disaster resilience by integrating it into disaster management plans. Moving on to Section 5 Impact on Nutritional Outcomes it looks at how energy influences outcomes with empirical evidence support. In Section 6, Malnutrition is discussed with a focus on malnutrition types alongside how access to energy can help reduce malnutrition. Section 7 covers Food Security by defining its components and showcasing how renewable energy improves food production efficiency as storage and distribution processes. Lastly in Section 8. Dietary Quality. We explore how renewable energy impacts food processing methods leading to access, to diets which ultimately enhances dietary quality thanks to initiatives focused on renewable energy.

The paper wraps up, in Section 9 the Conclusion, where it outlines the discoveries, impacts on policy and implementation suggestions for research and closing reflections, on combining renewable energy, sustainable development and nutritional results.

2. Renewable and Cleaner Energy Initiatives

2.1. Definitions and Types of Renewable and Cleaner Energy Sources

Renewable energy refers to energy sourced from processes that are constantly replenished. Unlike fossil fuels that harm the environment renewable energy sources are sustainable and eco-friendly. The main types of energy include solar, wind, hydro, biomass and geothermal energy.

Solar power captures sunlight, through cells or solar thermal systems. PV cells convert sunlight into electricity directly while solar thermal systems use sunlight to heat fluids that create steam to power turbines, for generating electricity (Sabour & Hosseini 2020). The potential of energy is immense; the Earth receives solar energy in one hour than the world consumes in a year (Chu & Majumdar 2012).

Wind power is produced by converting wind currents into power using wind turbines. Wind farms can be located onshore or offshore; offshore wind farms typically have wind speeds and less visual impact. Global wind energy capacity has been rapidly. Reached 651 GW in 2019 (Yasmeen et al., 2023).

Hydropower harnesses the energy of flowing water to produce electricity. It is a form of energy and contributes around 16% to global electricity production (Yoshikawa & Anbumozhi 2022).

Large scale hydroelectric projects involve the construction of dams to form reservoirs while small scale initiatives harness river currents, without changes to the environment.

Biomass energy is sourced from materials like plants, agricultural leftovers and waste. It can be transformed into biofuels such as ethanol and biodiesel or directly used for heating and producing electricity. This energy source is considered friendly since the carbon dioxide released during combustion is balanced by the CO2 absorbed during biomass growth (Katuwal & Bohara 2009).

Geothermal energy taps into the heat stored beneath the Earth's surface. Geothermal power stations convert this energy into power and heat pumps are utilized for climate control in buildings. The geothermal potential is significant in areas with tectonic activity, like Iceland and Indonesia (Lund & Boyd 2016).

Each of these energy sources presents benefits and challenges. For instance, solar and wind power are intermittent and rely on weather conditions while hydropower and geothermal sources offer electricity generation. The selection of an energy source often hinges on location economic factors and technological considerations (Godwin et al. 2024).

2.2. Current Global Status and Trends in Renewable Energy Adoption

The use of energy has shown growth in recent years propelled by advancements, in technology, governmental support and a growing awareness of climate change. By 2020 renewables made up 29% of the electricity supply with wind and solar power experiencing expansion.

Europe has taken the lead in embracing energy with nations like Germany, Denmark and Spain making investments in wind and solar power. In Germany renewable sources accounted for 46% of electricity usage in 2020-a surge from 6.3% in 2000 (Gjonca, 2017). Denmark has also made strides with wind energy meeting 47% of its electricity needs in 2019 (Yoshikawa and Anbumozhi, 2022).

In the US renewable energy sources supplied 20% of electricity generation in 2020; specifically, wind contributed to 8.4% while solar accounted for 2.3% as outlined in Table 1. Initiatives at the state level-such as California's goal to achieve energy by 2045-are spurring considerable investments into renewable energy infrastructure.

China has emerged as a player, in energy production globally particularly excelling in solar and wind power generation.

In 2020 China topped the charts by adding 72 gigawatts of wind power and 48 gigawatts of power showcasing its leadership, in these sectors (Vostriakova, 2021). The governments dedication to curbing carbon emissions and enhancing air quality has spurred investments in renewable energy ventures.

Renewable energy is playing a role in extending electricity access in developing nations. For example, off-grid solar systems are now bringing electricity to millions of households in Saharan Africa. Kenya, Tanzania and Ethiopia stand out as leaders in embracing off grid solutions, which not enhance energy accessibility but also boost economic growth (Zhang, 2022).

The COVID 19 pandemic has had repercussions on the energy arena causing delays in project execution and disruptions in supply chains. Nevertheless, the pandemic has underscored the resilience of energy setups. Stressed the importance of transitioning to sustainable energy sources. Governments worldwide have included investments in energy as part of their economic recovery strategies with a focus on creating employment opportunities and reducing carbon emissions (Yoshikawa and Anbumozhi 2022).

Technological breakthroughs play a role in advancing the efficiency and scalability of energy systems. In the realm of power perovskite solar cells show promise, for boosting efficiency levels while cutting down costs.

Perovskite solar cells have reached efficiency levels of over 25%. Researchers are working to enhance their durability and practicality for use (Sabour and Hosseini 2020).

In the realm of wind energy advancements like turbines floating wind farms and cutting-edge materials are boosting performance while lowering costs. The Haliade X turbine by GE Renewable Energy stands as the one with a capacity of 12 MW capable of supplying power to around 16,000 households yearly. Floating wind farms, designed for waters with winds are also gaining popularity, exemplified by projects like the Hywind Scotland wind farm (Zhang, 2022).

Hydropower technology is benefiting from designs in turbines and eco-friendly small-scale systems. Fish friendly turbines and run of river setups that do not rely on reservoirs are lessening the impact of hydropower initiatives (Yoshikawa and Anbumozhi, 2022). Furthermore, pumped storage hydropower is being utilized to stabilize energy sources by storing surplus energy during low demand periods and releasing it during peak times.

Advancements in biomass energy involve the progression of second-generation biofuels that utilize food sources, like agricultural remnants and algae.

Biofuels have been showing results, with reduced impact compared to the earlier versions derived from food crops (Yoshikawa and Anbumozhi, 2022). Advancements in digestion and gasification methods are also making biomass energy production efficient.

In the realm of energy there are improvements in enhanced systems (EGS) which involve creating artificial reservoirs in hot dry rock formations to extract heat. This technology has the potential to expand the reach of energy to areas beyond those with hydrothermal resources (Lund and Boyd 2016). Furthermore, applications like district heating and greenhouse agriculture are increasingly utilizing energy.

Energy storage technologies play a role in integrating energy into our power grids. Lithium-ion batteries and pumped hydro storage systems are players in this field. The capacity, efficiency and cost of battery storage systems are continuously improving, with a projected capacity of 250 GW by 2030 (Baranowski et al., 2022). Innovations such, as solid-state batteries and flow batteries are further enhancing the capabilities of energy storage solutions.

2.3. Case Studies of Successful Renewable Energy Projects

Numerous real-life examples showcase the execution of energy initiatives worldwide. For instance, in Morocco the Noor Ouarzazate Solar Complex, hailed as one of the Concentrated Solar Power (CSP) plants produces 580 MW of electricity ample to supply power to more, than a million households. This endeavor has notably lessened Morocco's dependence on fuels. Aims to source 52% of its electricity from renewable sources by 2030 (Zhang, 2022).

Germanys Energiewende policy has spurred investments in energy especially in wind and solar power. By introducing feed in tariffs and other incentives to encourage the adoption of energy sources Germany achieved a milestone where renewables accounted for 46% of its electricity consumption in 2020 with plans to elevate this figure to 65% by 2030 (Gjonca, 2017).

In Kenya the Lake Turkana Wind Power project stands out as Africa's wind farm with a capacity of 310 MW catering for around 17% of the nation's power requirements. Apart from enhancing energy accessibility this initiative has also bolstered job creation and economic development within the area (Yaffe, and Segal-Klein, 2023).

The US has witnessed progress in energy ventures, at both state and federal levels. The United States has seen significant growth in renewable energy projects at both the state and federal levels. The Ivanpah Solar Electric Generating System, located in California stands as one of the worlds thermal facilities generating 392 MW of power to supply electricity for more, than 140,000 households. This initiative has played a role in California's progress towards achieving its target of relying on clean energy by 2045 as shown in Figure 1 (Ho, & Christian, 2015).

Table 1 Current Global Status and Trends in Renewable Energy Adoption

Region	Status	Key Points	Technological Innovations
Global Overview	Renewables: 29% of global electricity generation (2020)	Wind and solar power show fastest growth rates	Perovskite solar cells, larger wind turbines, advanced battery storage systems
Europe	Leading region in renewable energy adoption	Germany: 46% renewable electricity (2020); Denmark: 47% wind energy (2019)	Fish-friendly turbines, floating wind farms
United States	20% of electricity from renewables (2020)	Wind: 8.4%, Solar: 2.3%; state initiatives like California's 100% clean energy by 2045	Haliade-X turbine with 12 MW capacity, advancements in energy storage technologies
China	Largest producer of renewable energy	Added 72 GW of wind and 48 GW of solar in 2020	Massive investments in renewable projects driven by government goals for emission reductions
Developing Countries	Key role in expanding electricity access	Off-grid solar systems in sub-Saharan Africa (Kenya, Tanzania, Ethiopia)	Affordable and scalable off-grid solar solutions, small-scale hydropower systems
Impact of COVID-19	Delays in projects, supply chain disruptions	Highlighted resilience and importance of renewable energy	Governments including renewables in economic recovery plans

In India the Kurnool Ultra Mega Solar Park boasts a capacity of 1,000 MW. Ranks among the globes most substantial solar parks. It caters to the energy needs of over 800,000 homes. Has been instrumental in supporting India's goal of reaching a renewable energy capacity of 175 GW by the year 2022 (Bansal, 2021).

Iceland has set an example with its energy endeavors effectively utilizing its volcanic activity for sustainable power generation. 90% of households benefit from geothermal heating while more than a quarter of the nation's electricity is derived from geothermal sources. The Hellisheidi Power Station serves as Iceland's plant, capable of producing 303 MW of electricity and an additional 400 MW, in thermal energy output.

Figure 1 Illuminated receivers at ISEGS, Feb. 2014 (Ho, & Christian, 2015)

In Figure 1, we see the Ivanpah Solar Electric Generating System (ISEGS) made up of three power towers that generate 392 MW on a 14.2 km2 (3500 acres) plot of desert land, in California. Then 170,000 heliostats with 2.6 million meters of mirrors redirect and focus sunlight, towards the receivers located at the summits of the 140 m (459 ft) towers, which then create steam for the power cycle.

3. Sustainable Development Goals and Energy

3.1. Overview of SDGs Related to Energy

The SDGs put forth by the United Nations in 2015 are designed to tackle challenges and work towards a sustainable future by the year 2030. Energy plays a role, in these goals impacting growth, environmental sustainability and social fairness. Among the 17 SDGs there is an emphasis on energy with SDG 7 known as " Clean Energy " taking center stage according to Table 2.

SDG 7 aims to provide "reliable, sustainable and modern energy access for all." This objective comprises five targets.

- By 2030 ensure that everyone has access to cost reliable energy services.
- By 2030 significantly boost the proportion of energy in the energy mix.
- By 2030 double the worldwide rate of progress in enhancing energy efficiency.
- By 2030 promote collaboration to support research and technology, for energy access.
- By 2030 enhance infrastructure development and technology upgrades to provide sustainable energy services in developing nations (Krannich & Reiser 2021).

Additionally, SDG 7 is closely intertwined with objectives.

SDG 13 also known as Climate Action stresses the importance of taking steps to address climate change, which is greatly impacted by the energy industry. Energy production and consumption contribute to, then 70% of greenhouse gas emissions (Vostriakova, 2021). Furthermore SDG 3 focused on Good Health and Wellbeing is linked to reducing pollution and enhancing health outcomes by adopting energy sources (Smith et al., 2019).

A significant number of people still do not have access to electricity. By the year 2020 around 759 million individuals were living without electricity with a concentration, in Saharan Africa and South Asia (Zhang, 2022). Meeting the targets of SDG 7 will require an effort to extend energy accessibility through sustainable and eco-friendly renewable energy sources.

3.2. The Role of Renewable Energy in Achieving These Goals

Renewable energy plays a role, in achieving SDG 7 and other related objectives by offering ecofriendly alternatives to traditional fossil fuels. Sources like solar, wind, hydro and biomass are essential for reducing emissions, enhancing energy security and promoting development.

3.2.1. Solar Energy

Solar power has become an energy option thanks to its widespread availability and decreasing costs. As of 2020 the global capacity of PV systems was around 707.5 gigawatts (GW) with countries such as China, the US and India leading in installations (Yoshikawa & Anbumozhi 2022). Solar energy aids in achieving SDG 7 by providing power solutions in rural areas where extending the electricity grid is challenging.

3.2.2. Wind Energy

Wind power is another player with a capacity of 743 GW by the end of 2020. Europe, North America and Asia are regions harnessing wind power. Offshore wind projects are growing rapidly with developments in the North Sea and East Asia showing promise, for large scale electricity generation (Yasmeen et al., 2023).

3.2.3. Wind power

Initiatives not aid in achieving Development Goal 7 but also play a role, in job creation and boosting local economies thereby contributing to Sustainable Development Goal 8 which focuses on promoting decent work and economic growth (Yasmeen, et, al., 2023).

3.2.4. Hydropower

Being the source of energy constitutes about 16% of global electricity generation boasting an installed capacity exceeding 1,330 GW (Yasmeen et al. 2023). Hydropower projects align with Development Goal 7 by furnishing consistent electricity supply essential, for industrial operations and urban progress.

3.2.5. Biomass energy

Table 2 Overview of SDGs Related to Energy

SDG	Description	Targets	Interconnections
SDG 7	Affordable and Clean Energy	- Universal access to modern energy services - Increase renewable energy share in global energy mix - Improve energy efficiency	Linked with SDG 13 (Climate Action) through reducing greenhouse gas emissions Intersects with SDG 3 (Good Health and Well-being) by reducing pollution and health risks Supports SDG 8 (Decent Work and Economic Growth) by creating jobs in the renewable sector
SDG 13	Climate Action	Urgent action to combat climate change and its impacts	Energy production and consumption account for over 70% of global greenhouse gas emissions
SDG 3	Good Health and Well-being	Reducing air pollution, improving health outcomes	Cleaner energy sources mitigate health issues like respiratory and cardiovascular diseases
SDG 8	Decent Work and Economic Growth	Creating jobs and promoting sustainable economic growth	Renewable energy projects offer employment opportunities, promoting economic development
Universal Access	759 million people lack electricity (2020)	Expanding access to renewable energy in developing regions	Critical for achieving other SDGs related to poverty, education, and gender equality

Which comes from materials provides an option for heating, electricity and transportation fuels. In 2020 modern bioenergy accounted for around 10% of the world's energy supply (Vostriakova, 2021). This form of energy supports Development Goal 7 by making use of residues, cutting down on waste and enhancing energy security.

Moreover, these sustainable energy sources play a role in addressing Development Goal 13 (Climate Action) by helping to combat climate change. For instance, the adoption of energy prevented an estimated 2.1 gigatons of CO2 emissions in 2020 (Vostriakova, 2021). The shift towards energy is crucial in order to keep temperature increases below the critical threshold of 2°C as outlined in the Paris Agreement.

In terms of growth and job opportunities the renewable energy industry is a driver for employment. Around 12 million individuals worldwide were employed in this sector in 2020 with solar PV technology being the employer (Vostriakova 2021). This aligns with Development Goal 8 (Decent Work and Economic Growth) as energy initiatives create job prospects, for both skilled and unskilled workers while fostering economic progress.

Furthermore, transitioning to renewable sources of energy helps reduce air pollution levels that contribute to millions of deaths each year (Smith et al., 2019).

Using energy sources can enhance the quality of the air resulting in health conditions ultimately contributing to SDG 3. Ensuring good health and wellbeing.

3.3. Policy Frameworks and International Collaborations Supporting Renewable Energy

Reaching the goals set by SDG 7 and related objectives necessitates policy frameworks and international cooperation. Various policy tools and collaborative initiatives have been put in place to encourage the adoption of energy and support development as depicted in Figure 2.

National Policies and Incentives; Nations worldwide have implemented diverse policies to foster the deployment of renewable energy. These measures encompass feed in tariffs, tax benefits mandates, for energy use and direct financial support. For example, Germanys Renewable Energy Sources Act (EEG) has played a role in boosting the proportion of renewables in its energy mix to 45.3% (Gjonca, 2017). Similarly, India's National Solar Mission aims to achieve a capacity of 100 GW by 2022 through government incentives and policy backing.

International Agreements and Organizations; The Paris Agreement, endorsed in 2015 stands as a treaty striving to limit global warming to below 2°C. This agreement encourages countries to present Nationally Determined Contributions (NDCs) detailing their climate action plans often incorporating targets for energy (United Nations Framework Convention on Climate Change, 2015). The International Renewable Energy Agency (IRENA) plays a role, in fostering collaboration by offering policy guidance and exchanging best practices to advance renewable energy initiatives.

Collaborative efforts between nations and international bodies play a role in expanding the use of energy. For instance, the International Solar Alliance, an initiative by India and France aims to attract $1 trillion in investments to implement power projects across 121 member countries by 2030. Another illustration is the Clean Energy Ministerial, where energy ministers from 29 countries come together to exchange knowledge and speed up the shift towards energy sources.

Securing financing is essential for energy ventures in less developed nations. The Green Climate Fund assists climate related projects in these regions with a portion designated for energy endeavors. By 2020 the GCF had sanctioned $7.2 billion for 129 projects worldwide. Moreover, partnerships between private sectors well as green bonds are emerging as effective means of financing such initiatives.

Progress in technology and research plays a role in driving down costs and enhancing the effectiveness of energy systems. Governments and global organizations invest in research and development (R&D) to foster innovation. As an illustration the European Union's Horizon 2020 initiative has allocated €5.7 billion towards energy research with a focus, on technologies, energy storage solutions and grid integration.

Building capital through education and training programs is crucial for the implementation of renewable energy solutions. Programs like the IRENA Renewable Energy Learning Partnership offer courses, workshops and educational materials to equip individuals with the skills for the renewable energy sector (Vostriakova, 2021).

In summary renewable energy plays a role in achieving the SDG 7. The global shift towards energy does not combat climate change but also boosts economic growth enhances public health and strengthens energy security. Effective

policy frameworks, international partnerships and innovative financing mechanisms are vital to support this transition and unlock the potential of energy in promoting sustainable development.

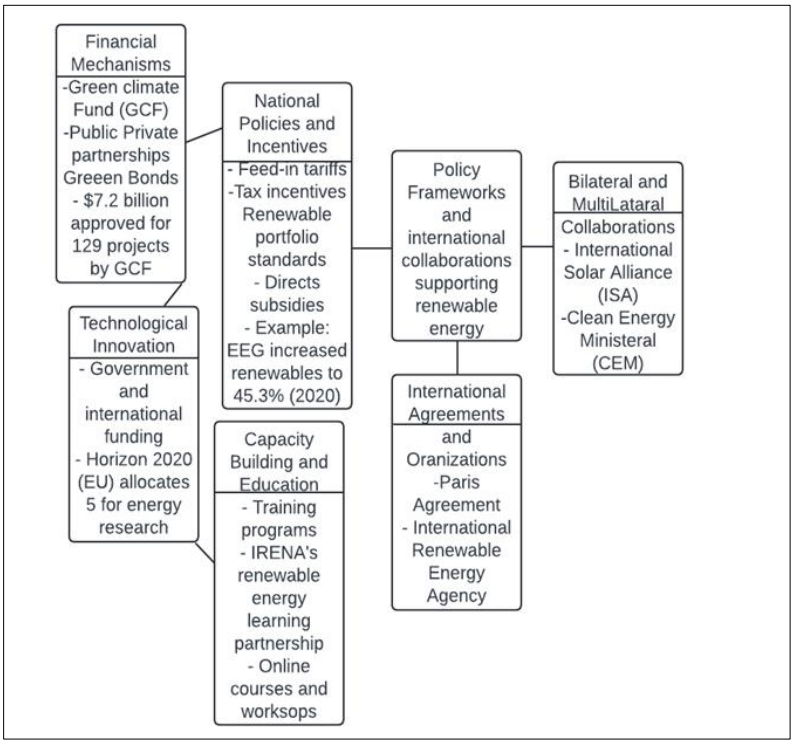

Figure 2 Policy Frameworks and International Collaborations Supporting Renewable Energy

Figure 2 illustrates the various policy frameworks and international collaborations that support the adoption and expansion of renewable energy. It starts with national policies and incentives, such as feed-in tariffs, tax incentives, renewable portfolio standards, and direct subsidies. An example is Germany's Renewable Energy Sources Act (EEG), which increased the share of renewables to 45.3% in 2020.

Next, it highlights international agreements and organizations like the Paris Agreement and the International Renewable Energy Agency (IRENA), which play a crucial role in promoting global cooperation for renewable energy adoption.

Bilateral and multilateral collaborations, such as the International Solar Alliance (ISA) and the Clean Energy Ministerial (CEM), facilitate knowledge sharing and accelerate clean energy transitions.

The diagram also includes financial mechanisms like the Green Climate Fund (GCF), which supports climate projects with significant funding for renewable energy initiatives. Public-private partnerships and green bonds are emerging as effective financing methods.

Technological innovation is supported by government and international funding, with programs like the EU's Horizon 2020 allocating €5.7 billion for energy research.

Finally, capacity building and education are essential for the sustainable deployment of renewable energy, with initiatives like IRENA’s Renewable Energy Learning Partnership offering online courses and workshops to develop the necessary skills in the renewable energy sector.

4. Disaster Management Strategies

4.1. Overview of Disaster Management and Its Relevance to Energy Infrastructure

Disaster management involves the planning, response and recovery efforts aimed at reducing the impact of both humans made disasters. It is crucial to have disaster management in place to safeguard services and infrastructure such as energy systems. The resilience of energy infrastructure plays a role as disruptions in energy supply can worsen the

effects of disasters on health, safety and economic stability. Having strong and adaptable energy infrastructure can help it withstand disasters better and recover faster ensuring a flow of electricity and other vital forms of energy needed for emergency services and recovery operations (Bashiru et al., 2024).

The significance of energy infrastructure in disaster management has been emphasized through incidents where energy systems were compromised during disasters leading to prolonged recovery periods and increased vulnerability among affected communities. For instance, Hurricane Maria, in 2017 severely damaged Puerto Ricos energy grid resulting in power outages that hindered relief efforts and worsened the situation (Cutter et al., 2012). This highlights the importance of incorporating energy infrastructure into disaster preparedness strategies.

4.2. The Impact of Renewable Energy on Disaster Resilience

Disaster management involves the planning, response and recovery efforts aimed at lessening the impact of both man-made disasters. It is crucial to have disaster management in place to ensure that essential services and infrastructure such, as energy systems remain functional. The resilience of energy infrastructure plays a role as any disruptions can worsen the effects of disasters on health, safety and economic stability. A sturdy and adaptable energy infrastructure is better equipped to withstand and bounce back from disasters guaranteeing a supply of electricity and other vital forms of energy needed for emergency services and recovery operations (Bashiru et al., 2024).

Renewable energy technologies like power, wind power and micro hydropower can improve disaster resilience by offering dependable energy sources that are less vulnerable to failures in centralized grids typically seen during disasters. These renewable energy systems can operate independently from the power grid ensuring a supply of energy during emergencies and post disaster periods as outlined in Table 3. For example, PV systems with battery backup can provide emergency power to shelters, medical facilities and communication networks—supporting emergency response efforts effectively (Idoko et al., 2024).

Decentralized renewable energy systems also help reduce risks linked with energy infrastructure that can be a point of failure, during disasters.

Distributing energy production to sites allows renewable energy systems to guarantee a power supply even if certain parts of the grid are affected. This backup is vital for sustaining services in times of disaster recovery (Mahama, et al., 2021).

4.3. Strategies for Integrating Renewable Energy into Disaster Management Plans

Incorporating energy, into disaster preparedness plans involves approaches, such as setting up microgrids using portable renewable energy units and integrating renewable energy into community resilience strategies. Microgrids are small scale power systems that can operate independently from the grid during emergencies offering electricity. These setups harness sources of energy and are built to function autonomously guaranteeing uninterrupted power supply in crucial locations (Poudineh, and Jamasb, 2014). Portable renewable energy units like panels and wind turbines can be swiftly dispatched to disaster-stricken areas for energy assistance. They play a role in supporting services such as clean water supply, healthcare facilities and communication networks thus enhancing the efficiency of disaster response efforts (Kusakana, 2016). Furthermore, educating communities about the advantages of energy and incorporating energy systems, into local disaster management plans are key components of enhancing community resilience.

4.4. Case Studies of Disaster Management Supported by Renewable Energy Solutions

Numerous real-life examples demonstrate the incorporation of energy solutions into disaster response plans. For instance, following the earthquake and tsunami that struck Japan in 2011 renewable energy systems proved instrumental in aiding the recovery efforts. Evacuation centers and public buildings benefited from the installation of PV systems ensuring a power supply crucial for communication, lighting and heating needs. This can be seen in Figure 3. Similarly in the aftermath of Hurricane Sandy in 2012 the utilization of solar powered generators supplied electricity to impacted regions supporting disaster reconstruction endeavors while reducing reliance on conventional fuel-based generators vulnerable to disruptions, in the supply chain.

Table 3 The Impact of Renewable Energy on Disaster Resilience

Aspect	Description	Benefits	Examples
Decentralized Energy Systems	Renewable energy systems that operate independently of the main power grid	Ensures continuous power supply during disasters	Solar PV systems with battery storage providing backup power to emergency shelters and hospitals
Redundancy and Reliability	Distributed energy generation across multiple locations	Reduces risk of total power loss	Wind turbines and micro-hydropower systems continuing operation even if part of the network is damaged
Mobile Renewable Energy Units	Portable solar panels and wind turbines deployed to disaster-affected areas	Provides immediate energy relief	Portable solar panels used for emergency communication systems and water purification units
Enhanced Community Resilience	Incorporation of renewable energy in community disaster management plans	Improves community's ability to withstand and recover from disasters	Community training programs on the use of renewable energy systems for disaster preparedness

In another instance, the integration of wind energy into the disaster management plan of the Philippines proved beneficial during Typhoon Haiyan in 2013. The wind farms in the region continued to operate during and after the typhoon, providing essential power to critical infrastructure and helping to stabilize the grid, which faced significant damage from the storm (Sinha, et, al., 2021).

5. Impact on Nutritional Outcomes

5.1. Overview of Nutritional Outcomes: Malnutrition, Food Security, and Dietary Quality

The health of the public and their overall well-being heavily rely on outcomes. Essential factors include malnutrition, food security and the quality of one's diet. Malnutrition, which encompasses both undernutrition and overnutrition can result in health problems, like growth weakened immunity and chronic illnesses as detailed in a study by Black et al. In 2013. Worldwide around 149 million children under the age of five are affected by growth with 45 million facing wasting conditions according to Katoch (2022).

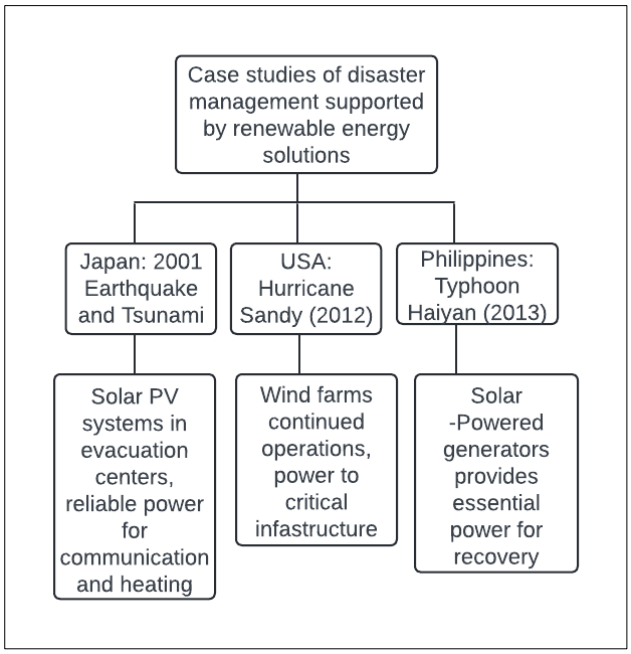

Figure 3 Case Studies of Disaster Management Supported by Renewable Energy Solutions

Food security is defined by the FAO as having access to safe and nutritious food to lead a healthy life. Despite this definition over 820 million people worldwide still suffer from hunger while many others face food insecurity due to challenges, conflicts and environmental issues as highlighted by FAO (2021).

Dietary quality focuses on the variety and nutritional value of diets consumed. Poor dietary choices can lead to deficiencies in nutrients affecting two billion individuals globally according to Graham et al. In 2007. Improving quality involves ensuring access to a range of nutrient rich foods, like fruits, vegetables and protein sources.

Table 4 offers an overview of aspects related to nutritional outcomes addressing malnutrition, food security issues and dietary quality concerns.

Malnutrition is when someone doesn't get the nutrients from their diet, which can lead to issues, like stunting or being overweight. It talks about how many kids are affected and how it can affect their thinking, physical growth and even increase the risk of death.

Food Security means having healthy food to stay well. The information shows hunger numbers. How the COVID 19 situation might make things worse highlighting how important it is, for keeping economies stable improving quality of life and protecting public health.

Dietary Quality involves having a mix of foods to get all the nutrients you need. It mentions that 2 billion people lack nutrients and explains how this can affect growth immunity levels and chances of getting long term illnesses.

Table 4 Key Aspects of Nutritional Outcomes: Malnutrition, Food Security, and Dietary Quality

Aspect	Description	Key Statistics	Impact
Malnutrition	Condition resulting from an imbalanced diet, including undernutrition and overnutrition	149 million children Leads to impaired cognitive and physical development Increased risk of mortality under 5 are stunted45 million children under 5 suffer from wasting	Leads to impaired cognitive and physical development Increased risk of mortality
Food Security	Consistent access to sufficient, safe, and nutritious food to maintain a healthy life	Over 820 million people suffer from hunger COVID-19 pandemic could increase this number by 132 million	Affects economic stability and quality of life, Essential for public health and development
Dietary Quality	Adequacy and diversity of diet, ensuring intake of necessary nutrients for health and well-being	2 billion people suffer from micronutrient deficiencies	Impacts growth, immunity, and chronic disease risk
Indicators	Measures of nutritional outcomes including Dietary Diversity Score (DDS), Healthy Eating Index (HEI)	Higher DDS linked to 20-50% reduction in micronutrient deficiencies 10-point increase in HEI reduces chronic disease risk by 7-8%	Used to assess and improve nutritional status, Important for designing nutrition interventions

Indicators, like the Dietary Diversity Score (DDS) and Healthy Eating Index (HEI) are utilized to evaluate results. The data presented emphasizes that elevated scores, in these indicators are linked to levels of deficiencies and decreased risk of chronic diseases emphasizing their significance in evaluating and enhancing nutritional well-being.

5.2. Mechanisms through Which Renewable Energy Influences Nutritional Outcomes

Renewable energy can have an impact, on nutrition outcomes through ways;

5.2.1. Boosting Agricultural Productivity

Technologies like powered irrigation systems can enhance crop yields by ensuring a water supply ultimately supporting food security and reducing hunger levels as highlighted in Burney et al. (2010).

5.2.2. Enhancing Food Storage and Preservation

Renewable energy sources can power refrigeration units and cold storage facilities reducing food losses after harvesting. In developing nations inadequate storage facilities contribute to up to 40% of harvest food wastage. Solar driven cold storage solutions help prolong the shelf life of items ensuring food availability and quality as discussed in Affognon et al. (2015).

5.2.3. Supporting Food Processing and Value Addition

Renewable energy plays a role in aiding food processing tasks like milling, drying and packaging which add value to products and improve their market appeal. This can enhance diversity by making processed and fortified foods more accessible (Bala & Hossain 2010).

5.2.4. Fostering Economic Empowerment

By enabling access, to energy sources economic activities can flourish with the creation of job opportunities and increased household incomes.

With increased household incomes families have the means to access a variety of foods ultimately boosting their overall nutritional well-being (Ijiga et al., 2024).

5.2.5. Health and Hygiene

Renewable energy can power healthcare facilities ensuring that crucial services, like vaccinations and maternal care are readily available. Strengthening health infrastructure can help combat malnutrition by addressing health issues that impact status, such, as diseases (Haines et al., 2009).

In Figure 4 we can see the ways in which renewable energy influences outcomes. It focuses on five areas;

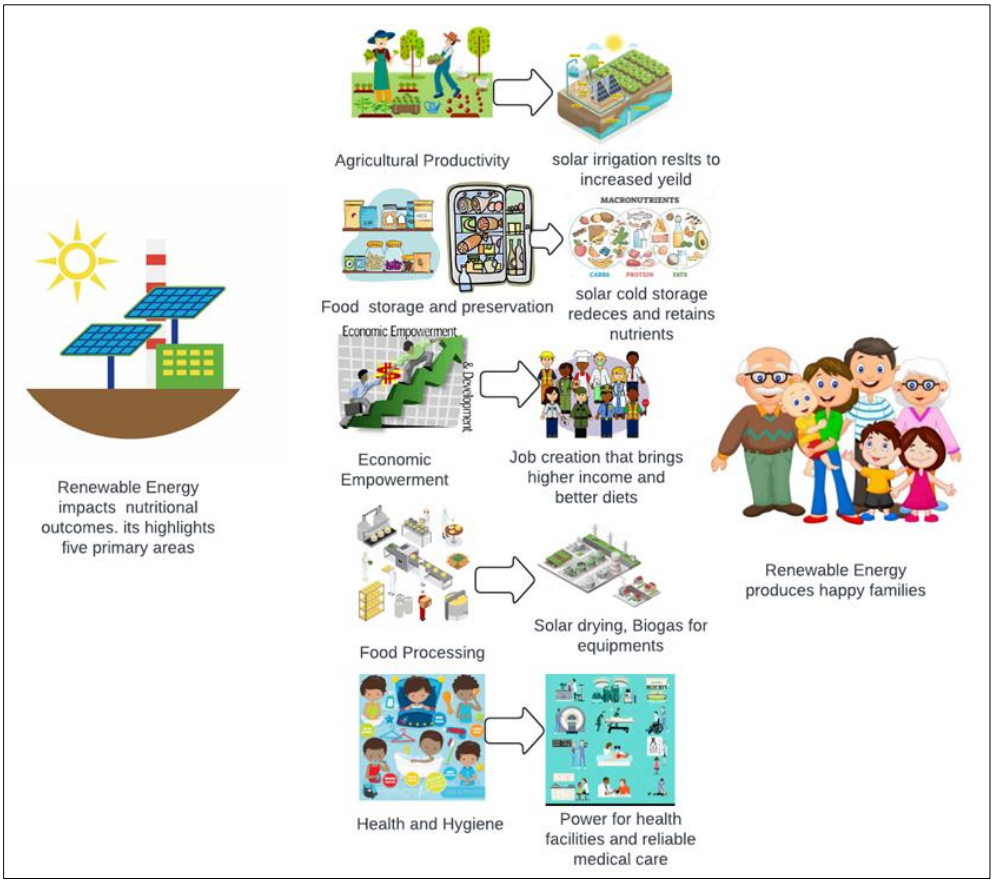

Figure 4 Renewable Energy Influences on Nutritional Outcomes

- Agricultural Productivity; Solar irrigation systems result in crop yields and consistent food production directly enhancing food availability and nutritional outcomes.
- Food. Preservation; Solar cold storage helps reduce harvest losses guaranteeing the availability of nutritious foods by extending the shelf life of perishable items.
- Economic Empowerment; Renewable energy initiatives generate employment opportunities. Boost household incomes, enabling families to access diets and enhance their overall nutrition.
- Food Processing: Solar drying and biogas powered tools play a role, in improving food processing making a variety of processed and preserved foods available. This helps in promoting a diet that's rich in nutrients.
- Health and Hygiene: The use of energy ensures that health facilities have power supply leading to better medical care and reducing health problems associated with fossil fuel usage. This in turn supports wellbeing.

Overall, these approaches show how renewable energy can have an impact, on improving nutrition through enhanced food production, storage methods, economic stability and healthcare services.

5.3. Empirical Evidence Linking Renewable Energy Initiatives to Improved Nutritional Outcomes

Several research studies present real world evidence connecting the adoption of energy projects, with impacts on nutrition outcomes.

5.3.1. Adoption of Solar Powered Irrigation Pumps in India

A study examining the use of irrigation pumps in India revealed enhancements in crop yields and food security. Farmers who utilized pumps reported a 40% rise in production leading to an increase in household food availability (Jha, 2023).

5.3.2. Introduction of Solar Refrigeration Systems in Kenya

In Kenya the implementation of solar refrigeration systems for dairy products resulted in a decrease in milk spoilage rates from 30% to below 5%. This not boosted food security. Also improved dietary quality by ensuring access to nutritious dairy products (Affognon et al., 2015).

5.3.3. Harnessing Wind Energy for Rural Electrification

An initiative employing wind energy for electrification purposes in Ethiopia demonstrated that households with access to energy sources experienced higher incomes and better dietary diversity compared to those lacking such access. This positive change was linked to increased opportunities and reduced dependency on biomass for cooking (Yasmeen et al., 2023).

5.3.4. Biogas Programs Implementation in Nepal

The establishment of biogas programs in Nepal aimed at converting animal waste into energy, for cooking and lighting yielded health benefits.

Households that utilize biogas experienced reduced cases of ailments. Saw an improvement, in their nutritional well-being as a result of enhanced cooking methods (Katuwal and Bohara 2009). These instances showcase the ways in which sustainable energy projects can boost results, such, as elevating agricultural efficiency refining food preservation techniques and ultimately contributing to improved health and financial security.

6. Malnutrition

6.1. Definition and Types of Malnutrition

Malnutrition occurs when the body lacks or has an excess of nutrients due, to a diet. There are two forms of malnutrition: undernutrition and overnutrition. Undernutrition includes stunting (height for age) wasting (weight for height) and underweight (low weight for age). On the hand overnutrition involves being overweight, obese and developing diseases like heart disease, stroke, diabetes and certain cancers (Black et al., 2013). Stunting affects 22% of children under five globally. Can lead to hindered cognitive and physical growth (Katoch, 2022). Wasting affects 7.3% of children and is linked to a higher risk of mortality. Overnutrition is on the rise with over 1.9 billion adults estimated to be overweight, by the WHO including 650 million who are categorized as obese.

6.2. The Relationship Between Renewable Energy Access and Malnutrition Reduction

The utilization of energy sources plays a role, in addressing malnutrition through various channels. Renewable energy has the potential to boost productivity improve food storage methods and create economic opportunities all leading to better nutrition outcomes as illustrated in Figure 5 (Burney et al., 2010).

For example, the implementation of solar powered irrigation systems enables year-round farming and higher crop yields, thereby increasing food availability and diversity in diets. In countries like India, the adoption of irrigation has been associated with a 40% rise in crop production directly contributing to food security and lowering malnutrition rates (Jha, 2023).

The use of energy technologies for food storage, such as solar powered refrigeration units help mitigate post-harvest losses. In regions like Saharan Africa where almost 40% of harvested food is lost due to inadequate storage facilities solar refrigeration has notably decreased spoilage rates. This ensures access to food and improves overall nutrition (Affognon et al., 2015).

Furthermore, renewable energy can fuel food processing industries that play a role in enhancing food safety and nutritional value through fortification and preservation processes. This is especially vital in areas where access, to foods is limited (Bala & Hossain 2010).

Economic empowerment, through the use of energy initiatives also enables families to access a variety of nutritious foods, which helps in tackling both malnutrition and overnutrition issues. In Figure 5 the connection between energy availability and the reduction of malnutrition is illustrated through five mechanisms;

- Increased Agricultural Productivity; The use of powered irrigation systems results in crop yields and more consistent food production, directly impacting food availability and reducing malnutrition.
- Enhanced Food. Preservation; Solar cold storage units decrease harvest losses and ensure a stable food supply by prolonging the shelf life of perishable items.
- Financial Independence; By implementing energy projects job opportunities are. Household incomes rise, enabling families to afford healthier foods that combat malnutrition.
- Improved Diet Diversity; Renewable energy technologies like drying and biogas for food processing make it easier for people to access diets rich, in nutrients enhancing overall dietary quality.

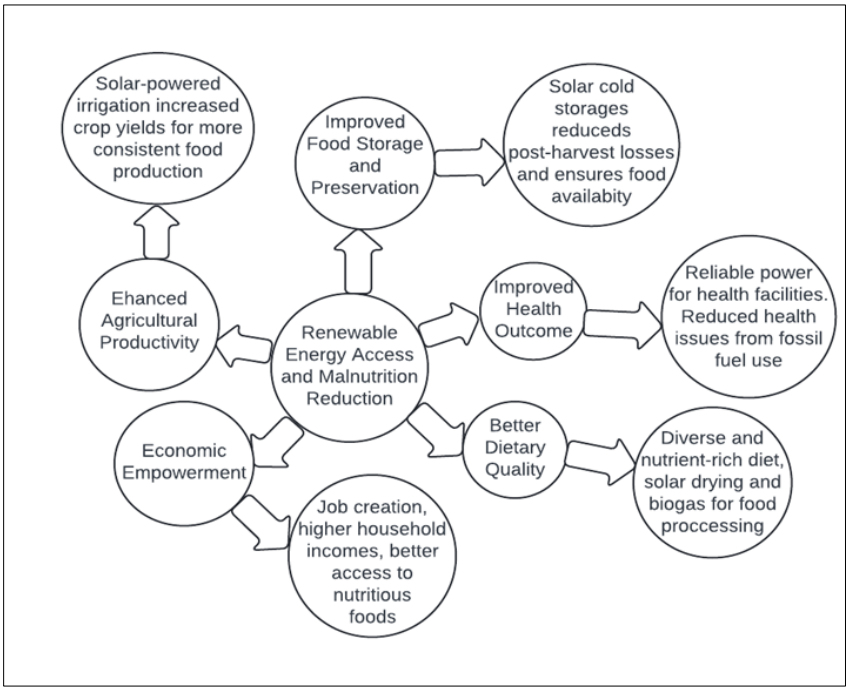

Figure 5 How Renewable Energy Access Reduces Malnutrition

Improved Health Outcomes: Reliable power for health facilities ensures consistent medical care and reduces health issues related to fossil fuel use, supporting better nutritional health and reducing malnutrition rates.

These interconnected mechanisms show how renewable energy access can significantly reduce malnutrition by improving food production, storage, economic stability, dietary quality, outcomes.

6.3. Case Studies Demonstrating the Impact of Energy Projects on Malnutrition Rates

Several real-life examples demonstrate how renewable energy initiatives have had an impact, on alleviating malnutrition rates;

6.4. Solar Irrigation in Bangladesh

The implementation of irrigation pumps in Bangladesh has resulted in improved output and decreased seasonal food scarcity. Farmers who utilized these pumps saw a 15% rise in their household income allowing them to invest in food choices. This in turn led to a decline in child undernutrition rates as indicated by the data presented in Table 5 (Jha, 2023).

6.5. Biogas Programs in Nepal

In Nepal programs focused on converting animal waste into biogas for cooking and lighting purposes have positively influenced the well-being of households. These initiatives have reduced dependence on biomass resources leading to health outcomes and more time for income generating activities. Consequently, families have reported an increase in variety and a decrease in stunting and wasting cases (Katuwal and Bohara 2009).

6.6. Wind Energy in Ethiopia

An initiative involving wind energy deployment in Ethiopia has provided electricity access to local communities thereby enhancing food preservation and processing capabilities. Households with access to electricity generated by wind turbines exhibited scores for diversity and lower rates of child malnutrition compared to those, without such access (Yasmeen et al., 2023).

6.7. Solar Cooling, in Kenya

The use of powered refrigeration systems in the dairy industry in Kenya has led to a decrease in milk spoilage rates dropping from 30% to under 5%. This advancement has not boosted food security. Also elevated the quality of diets by guaranteeing a steady supply of wholesome dairy products. As a result, it has played a role, in improving nutritional well-being (Affognon, et al., 2015).

7. Food Security

7.1. Definition and Components of Food Security

Ensuring food security is a notion according to the Food and Agriculture Organization (FAO). It means that everyone should always have access, to nutritious food that suits their needs and preferences for a healthy lifestyle. This definition covers four aspects; availability, access, utilization and stability.

Availability concerns the existence of food. Is influenced by production, distribution and exchange systems to meet the populations dietary requirements.

Access involves how affordable and accessible food is based on individuals' preferences, income levels, market prices and social support systems. Utilization focuses on consuming food for absorption requiring a balanced diet, clean water, sanitation facilities and healthcare services. Lastly stability refers to the availability of food over time while withstanding climatic changes or political uncertainties.

Food security continues to be a challenge. As, per the FAO, around 690 million individuals suffered from hunger in 2019 a figure worsened by the impact of the COVID 19 outbreak possibly rising by as 132 million by the close of 2020 (FAO, 2021). Tackling these issues demands a strategy that involves incorporating energy to improve food cultivation, preservation and delivery.

7.2. How Renewable Energy Enhances Food Production, Storage, and Distribution

Renewable energy plays a role, in improving food security by influencing food production, storage and distribution. The use of energy technologies as illustrated in Figure 6 has brought about benefits to food production. For example, powered irrigation systems have transformed methods by ensuring a consistent water supply without relying on grid electricity or diesel fuel. In India the adoption of solar powered pumps has led to a 20 30% increase in crop yields compared to irrigation techniques as highlighted in Table 6 (Burney et al., 2010). These innovative systems not energy expenses but also contribute to sustainable farming practices while reducing environmental impact.

Table 5 Impact of Energy Projects on Malnutrition Rates: Case Studies

Case Study	Location	Energy Project	Impact on Malnutrition
Solar Irrigation Pumps	Bangladesh	Solar-powered irrigation systems	Increased agricultural productivity by 15%. Improved household food availability and nutrition
Biogas Programs	Nepal	Biogas plants converting animal waste	Reduced reliance on traditional biomass. Improved dietary diversity and reduced stunting and wasting
Wind Energy for Electrification	Ethiopia	Wind-powered electrification in rural areas	Higher dietary diversity scores. Reduced child malnutrition rates due to increased food storage and processing capabilities
Solar Cooling Systems	Kenya	Solar-powered refrigeration units	Reduced milk spoilage from 30% to less than 5%. Improved food security and dietary quality by ensuring availability of dairy products

In terms of storage solutions renewable energy plays a role in addressing harvest losses that make up around 40% of food wastage in developing nations due to insufficient storage facilities (FAO, 2021). Solar powered cold storage units help combat these losses by maintaining temperatures for items thereby prolonging their shelf life. Notably initiatives involving refrigeration projects in India have successfully decreased harvest losses by up to 30% for vegetables and fruits (Ijiga et al., 2024).

Furthermore, renewable energy advancements improve distribution networks through decentralized systems like wind power that provide electricity, for transportation and market infrastructure. In locations, with access to traditional power sources such as in Kenya, the use of solar powered refrigeration has extended the freshness of fish decreasing waste by 25% and guaranteeing that goods are delivered to markets in superior quality. Moreover, transitioning to renewable energy for transportation lessens dependence, on fuels lowers. Greenhouse gas emissions and supports an eco-friendlier food distribution network.

Figure 6 Agrivoltaics: Enhancing Agriculture with Renewable Energy (Whittaker, 2022)

The pictures show how renewable energy is combined with farming with panels placed above crop fields and grazing spaces. This innovative method, called agrivoltaics not produces energy but also improves agricultural output. It offers shade decreases water loss and supports irrigation systems leading to food security and nutrition.

7.3. Examples of Renewable Energy Projects Improving Food Security

Numerous renewable energy projects globally have demonstrated significant improvements in food security. In India, the "KUSUM" scheme aims to install solar pumps across the country, benefiting farmers by reducing dependency on diesel and grid electricity for irrigation. This initiative is expected to save farmers over $6 billion annually in energy costs and increase agricultural productivity as presented in Figure 7.

In Kenya, the "M-KOPA Solar" project has provided over 750,000 households with solar energy systems, enabling the use of solar-powered refrigeration for preserving milk and fish. This has led to a significant reduction in post-harvest losses and improved income for farmers and fishermen. Similarly, in Ethiopia, solar-powered irrigation has increased crop yields by 300%, demonstrating the profound impact of renewable energy on agricultural productivity (Burney et al., 2010).

In Vietnam, the "Biogas programmed for the Animal Husbandry Sector" has installed over 200,000 biogas plants, converting animal waste into energy. This not only provides a renewable energy source for cooking and heating but also produces high-quality organic fertilizer, boosting agricultural productivity and reducing the need for chemical fertilizers. This initiative has significantly improved food security by enhancing soil fertility and crop yields.

Many renewable energy initiatives worldwide have shown enhancements in ensuring food security. In India the "KUSUM" program is dedicated to setting up pumps benefiting farmers by reducing their reliance, on diesel and traditional electricity for irrigation. This effort is projected to save farmers than $6 billion in energy expenses and enhance agricultural output as detailed in Figure 7.

In Kenya the "M KOPA Solar" project has equipped over 750,000 households with energy systems allowing the use of solar powered refrigeration to preserve milk and fish. This has led to a decrease in harvest losses and an increase in earnings for farmers and fishermen. Similarly in Ethiopia solar powered irrigation has boosted crop yields by 300% showcasing the influence of energy on agricultural productivity (Burney et al., 2010).

In Vietnam the "Biogas programmed for the Animal Husbandry Sector" has established than 200,000 biogas plants that convert animal waste into energy. This not offers an energy source for cooking and heating but also generates premium organic fertilizer enhancing agricultural productivity and decreasing reliance, on chemical fertilizers. This endeavor has substantially enhanced food security by improving soil fertility and crop yields.

In Bangladesh, the initiative known as the "Solar Home Systems" project has successfully set up panels in, then 4 million households bringing electricity to rural areas. This has allowed for the use of pumps, for irrigation leading to water management in agriculture. Moreover, the implementation of solar powered lighting has enabled farmers to work hours ultimately boosting productivity and food output (Zhang, 2022).

These instances showcase how projects centered on energy can significantly bolster food security by enhancing production efficiency cutting down on harvest losses and ensuring a reliable distribution network. By harnessing energy technologies communities can create robust and sustainable food systems aligning with broader objectives of sustainable development and poverty reduction.

Figure 7 provides a representation of renewable energy initiatives that have played a key role in enhancing food security across diverse regions through increased agricultural productivity reduced post-harvest losses and enhanced water management.

In India there is the KUSUM Scheme which focuses on providing pumps, for irrigation. This initiative aims to reduce the reliance on diesel and grid electricity ultimately leading to an increase in productivity.

Similarly in Kenya the M KOPA Solar project is working towards implementing energy systems for areas and farms. The goal is to minimize harvest losses and boost income opportunities for farmers and fishermen.

In Ethiopia the focus is on Solar Irrigation projects that aim to introduce solar powered irrigation systems. This effort has resulted in a 300% increase in crop yields. Has enhanced overall agricultural productivity.

Vietnams Biogas programmed for Animal Husbandry involves setting up biogas plants that convert animal waste into energy. This does not provide energy for cooking and heating but also contributes to the production of organic fertilizer.

Lastly Bangladesh's initiative involves Solar Home Systems, which are aimed at providing energy solutions for households, in areas.

8. Dietary Quality

8.1. Definition and Indicators of Dietary Quality

Dietary quality refers to the extent to which an individual's diet adheres to dietary guidelines and provides the necessary nutrients for maintaining health, growth, and overall well-being. High dietary quality encompasses a balance of macronutrients (proteins, fats, and carbohydrates) and micronutrients (vitamins and minerals), alongside other factors such as food variety, safety, and accessibility (FAO, 2021). Indicators of dietary quality typically include measures like the DDS, which counts the number of different food groups consumed over a reference period, and the HEI, which evaluates the overall quality of diet against dietary guidelines. Another key indicator is the Nutrient Adequacy Ratio (NAR), which assesses whether specific nutrient intake meets the recommended dietary allowances. For instance, a high DDS correlates with better micronutrient intake, while a high HEI score is associated with reduced risks of chronic diseases such as obesity, cardiovascular disease, and type 2 diabetes (Ruel, 2003).

Quantitative data stresses the importance of dietary quality. Studies have shown that individuals with higher dietary diversity scores are 20-50% less likely to suffer from micronutrient deficiencies (Torheim et al., 2004). Moreover, a 10-point increase in HEI scores has been linked to a 7-8% reduction in the risk of chronic diseases. For example, a study by Torheim et al. (2004) found that dietary diversity was strongly associated with nutrient adequacy among women in Mali, with those having higher diversity scores showing significantly better nutritional outcomes.

Table 6 Renewable Energy Enhancements in Food Systems

Aspect	Renewable Energy Solution	Benefits	Examples
Food Production	Solar-powered irrigation systems	Increased crop yields, Reduced dependency on traditional energy sources	Solar pumps in India boosting crop yields
	Wind-powered water pumps	Enhanced water access for agriculture, Sustainable water management	Wind pumps in sub-Saharan Africa
Food Storage	Solar cold storage units	Reduced post-harvest losses, Extended shelf life of perishable goods	Solar refrigerators in rural Kenya
	Biogas refrigeration	Efficient and eco-friendly cooling solutions	Biogas fridges in Nepal
Food Distribution	Solar-powered transportation systems	Reduced transportation costs, Lower carbon footprint	Solar trucks for food delivery in the USA
	Renewable energy-powered supply chains	Improved efficiency, Consistent and reliable delivery	Solar and wind energy in food logistics

8.2. Influence of Renewable Energy on Food Processing and Access to Diverse Diets

Renewable energy plays a role, in improving food processing capabilities and increasing access to a variety of diets in areas with limited resources. By incorporating energy sources like solar, wind and bioenergy into food systems it can greatly enhance food production, processing, storage and distribution. Solar energy is being utilized more for food drying and preservation processes. Solar dryers harness the suns energy to remove moisture from food reducing harvest losses by up to 30% thus ensuring a more consistent food supply (Sharma et al., 2009). This not extends the shelf life of food. Also preserves its nutritional value. For instance, using dryers to dry fish in Tanzania led to retention of protein and essential fatty acids compared to traditional open air-drying methods (Bala & Hossain 2010).

Wind power can also play a role in enhancing quality by providing power for irrigation systems that support the cultivation of various crops. In regions, like Saharan Africa wind powered water pumps have enabled farmers to cultivate a range of fruits and vegetables promoting greater dietary diversity.

Bioenergy, sourced from materials serves as an energy option that supports food processing. Biogas systems, which transform farm waste into energy offer a solution, for fueling food processing machinery. In countries like India biogas

facilities have played a role in processing dairy products and grains enhancing the supply of nourishing foods (Bond and Templeton 2011).

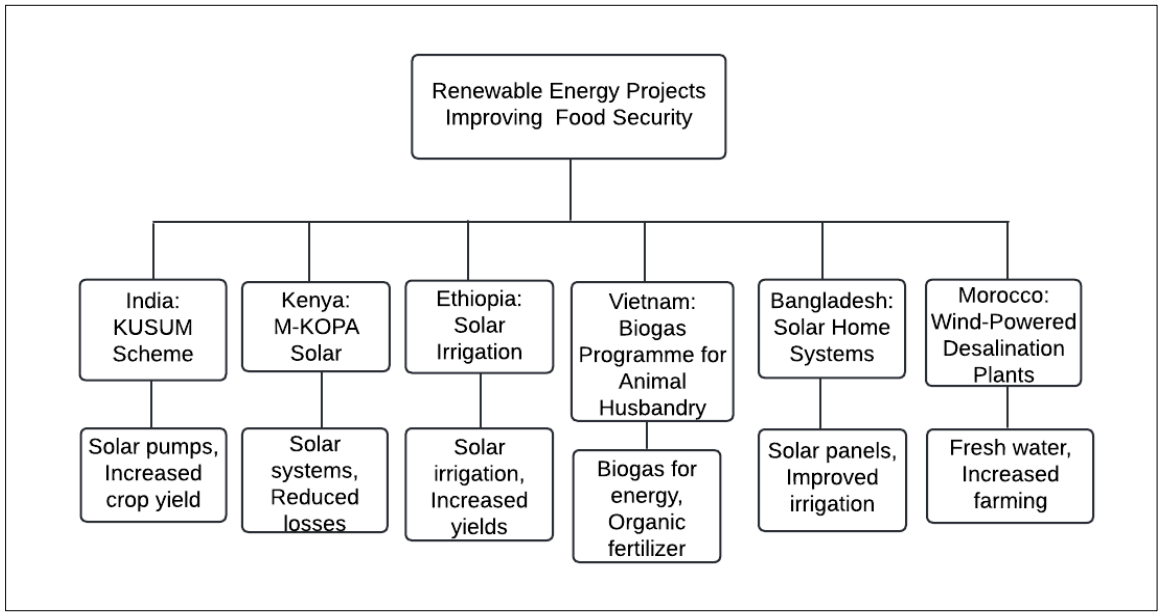

Figure 7 Examples of Renewable Energy Projects Improving Food Security

Moreover, renewable energy aids in expanding access to diets by enabling the development of cold chain infrastructure for storing and transporting perishable items such as dairy products, meat and fresh produce. For instance, powered refrigeration units have been effective in reducing spoilage and prolonging the availability of these foods in regions (Idoko et al., 2024). This ensures that communities have year-round access, to a range of foods significantly enhancing dietary quality.

8.3. Case Studies Showcasing Improvements in Dietary Quality Due to Renewable Energy Initiatives

Numerous real-life examples showcase how the introduction of energy projects has positively impacted the quality of diets. For instance, in Bangladesh, the implementation of solar powered irrigation systems has resulted in crop yields and a wider variety of crops being grown throughout the year including vegetables and fruits that were previously difficult to cultivate due, to water shortages. This has led to an improvement in diversity among farming communities with households reporting a 15% increase in the consumption of fruits and vegetables.

In Kenya the use of refrigeration units in areas has significantly improved food storage capabilities. These units have made it possible to store milk and dairy products which're sources of calcium and protein. Research indicates that households with access to refrigeration experienced a 25% increase in milk consumption contributing to enhanced quality and overall nutrition.

Similarly in India, the integration of biogas plants into areas has shown enhancements in dietary quality. The biogas produced from waste is utilized for cooking purposes. Powering food processing equipment enabling more efficient preparation of legumes and cereals. According to findings by the International Food Policy Research Institute (IFPRI) this initiative resulted in a 20% increase in protein intake, among participating households.

In a scenario wind driven desalination facilities, along the coasts of Morocco have granted communities with fresh water access, crucial for cultivating various crops. This advancement has empowered farmers to broaden their farming endeavors by including nourishing vegetables and fruits in their harvests thereby enriching the diet variety of residents (Ghaffour et al., 2013). These instances collectively highlight that sustainable energy projects can bring about enhancements in quality by improving food processing capabilities increasing the range of nutrient rich foods available and ensuring continual access to fresh produce throughout the year. The incorporation of energy, into food systems not promotes sustainable growth but also advances better nutrition and health outcomes.

9. Conclusion

9.1. Summary of Key Findings

This review paper explores the role that renewable and cleaner energy plays in achieving Development Goals (SDGs) and improving nutritional outcomes especially in addressing malnutrition, food security and dietary quality. By incorporating energy sources, like solar, wind and bioenergy into food systems there is enhancement in food production, processing, storage and distribution. This leads to direct and indirect benefits for outcomes by ensuring a supply of diverse foods. For instance, the use of energy in food drying processes has reduced harvest losses by up to 30% thereby improving food availability and quality.

Research findings suggest that renewable energy can have an impact on quality by increasing access to a variety of nutrient rich foods. The implementation of powered irrigation systems in Bangladesh has resulted in crop yields and diversification leading to a 15% rise in fruit and vegetable consumption among local communities. Similarly, the introduction of refrigeration units in Kenya has enhanced food storage capabilities resulting in a 25% increase, in milk consumption and better nutritional outcomes.

Additionally renewable energy promotes food security through improved food production efficiency well as storage and distribution capacities.

Wind driven water pumps and bioenergy solutions have empowered farmers in regions, like Saharan Africa and India to cultivate and process a wider variety of crops leading to enhancements in food security and reductions in malnutrition rates.

9.2. Policy and Practice Implications

The outcomes of this analysis hold implications for policy and practical applications. Decision makers should prioritize the incorporation of energy solutions into food systems to bolster food security and nutritional outcomes. This can be accomplished by offering subsidies and financial incentives to encourage the adoption of energy technologies in less developed regions. For example, enacting policies that promote the utilization of powered irrigation systems can notably boost agricultural productivity and food availability thereby mitigating malnutrition and food insecurity.

Furthermore, global collaborations and policy frameworks such as the Paris Agreement should be reinforced to encourage the adoption of energy. Governments and entities should allocate inter-resources towards research efforts aimed at enhancing the efficiency and affordability of energy technologies. Collaboration with enterprises and international development agencies is essential for expanding sustainable energy initiatives.

In terms of implementation there should be a focus on providing training programs, for communities to ensure the efficient deployment and upkeep of sustainable energy systems.

Teaching farmers how to use powered irrigation and drying systems for instance can improve crop yields and food preservation thereby boosting food security and dietary quality.

9.3. Future Research Directions

In terms of research directions, it is essential to explore the long-term effects of energy, on nutritional outcomes and sustainable development. Conducting studies will be crucial in evaluating the lasting effects of energy initiatives on aspects like food security, dietary quality and overall health. Furthermore, more research is necessary to comprehend the socio-cultural influences that play a role in the adoption of energy technologies across various regions.

Exploring the potential of emerging energy technologies such as bioenergy and microgrid systems in enhancing food systems and nutritional outcomes represents a significant focus for future research. Developing models that integrate energy, food systems and health outcomes will help in better anticipating and optimizing interventions.

Research efforts should also consider the impacts of renewable energy projects, on local ecosystems and food production systems.

For instance, studying the impacts of scale farms, on land usage and biodiversity can offer insights into sustainable practices that strike a balance between energy generation and environmental preservation.

9.4. Final Thoughts on the Integration of Renewable Energy, Sustainable Development, and Nutritional Outcomes

Incorporating energy sources into food systems offers a path towards achieving sustainable progress and enhancing nutritional outcomes. By diminishing dependence on fuels clean energy can alleviate the repercussions of energy production and support global endeavors to address climate change. The utilization of energy in farming and food processing can bolster food security diminish malnutrition. Enhance dietary standards especially in regions with limited resources.

To achieve progress, it is essential to confront the interconnected hurdles of energy accessibility, food security and nutrition. Clean energy provides a solution to these challenges by supplying sustainable energy for food cultivation and processing thereby ensuring a steady provision of nutritious meals. The case studies spotlighted in this evaluation underscore the advantages of energy projects in enhancing dietary standards and overall health results.

In summary the effective integration of energy into food systems necessitates efforts, from policymakers, researchers and professionals.

Harnessing the power of energy can help us take steps towards reaching the SDG improving nutrition results and promoting sustainable growth for the next generations.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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