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The Impact of Material Science on Renewable Energy Technologies

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ABSTRACT: Rapid increases in power generation from renewable sources are being advocated as part of the global strategy to reduce CO₂ emissions. Renewable energy technologies range from the well established, such as hydropower, to the emergent, such as biomass gasification. Each technology has its own individual materials requirements, to permit reductions in capital costs, to increase longevity in harsh environments, or to enable generating efficiency to be increased. Alternative energy technologies are greatly hindered by significant limitations in materials science. From low activity to poor stability, and from mineral scarcity to high cost, the current materials are not able to cope with the significant challenges of clean energy technologies. However, recent advances in the preparation of nanomaterials, porous solids, and nanostructured solids are providing hope in the race for a better, cleaner energy production. The technologies covered include wind, hydro, wave and tidal, waste and biomass combustion and gasification, geothermal, solar thermal, and solar photovoltaic. Relevant examples of the development of mesoporosity by a wide range of techniques are provided, including the preparation of hierarchical structures with pore systems in different scale ranges. Mesoporosity plays a significant role in catalysis, especially in the most challenging processes where bulky molecules, like those obtained from biomass or highly unreactive species, such as CO₂ should be transformed into most valuable products.

KEYWORDS: renewable sources, materials requirements, Renewable energy technologies, materials science, nanomaterials, nanostructured.

I. INTRODUCTION

Material science research is a multidisciplinary field that focuses on understanding the properties and behavior of different materials at the atomic and molecular levels. Over the years, significant advancements in material science have led to revolutionary breakthroughs across various industries, including electronics, energy, healthcare, transportation, and more. This study aims to explore some of the recent developments in material science research and their potential implications for a sustainable future. Material science research plays a pivotal role in the development of new materials and the enhancement of existing ones, with significant implications for numerous industries and technologies. These advancements have resulted in the discovery of novel materials with exceptional properties, paving the way for revolutionary applications in areas such as electronics, energy storage, healthcare, transportation, and environmental sustainability. Energy materials research tackles the challenges of energy generation, storage, and conversion. Advances in material science and engineering are critical to the development of economically viable technologies to address some of the grand socio-economic challenges of the twenty first century. This led him to conclude that a human population would eventually outstrip its ability to find and produce new sources of food, thus leading to a catastrophe that would bring the population down to a more sustainable level. Although agricultural innovations have enabled the support of much larger populations than Malthus could have ever imagined, the real question is whether this can be continued.

II. LITERATURE REVIEW

Nura Aliyu Kabuga, Aliyu Yusuf Ahmad (2018) This study assesses the public perceptions and acceptance of renewable energy technologies in Kaduna Metropolis, Nigeria. The research study used a proportional odds model

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known in the categories of ordinal models as an ordinal logit regression model in conducting its econometric modelling. It also employed a sample of 140 respondents, and the estimated result was obtained using Stata 15 software. The study presented the respondents with different renewable energy technology options, and the finding suggests that the respondents perceived the different dimension of benefits resulting from these renewable energy technologies starting from economic to environmental and social benefits. The results also imply that the respondents were particularly more concerned about economic benefits than environmental benefits associated with renewable energy technologies. It was also obvious from the findings presented that the respondents preferred solar energy technology as a means of diversifying energy sources in the study area.

Yosoon Choi et al (2017) In this study, applications of renewable energy technologies in the oil and gas industry were analyzed. A number of photovoltaic systems were investigated as applications for providing electric power to production facilities (i.e. the oil fields of Midway-Sunset, Kern River and Louisiana Bayou in the United States). Wind power systems were studied in the oil fields of Suizhong 36-1 (China), Beatrice (UK) and Utsira Nord (Norway). The geothermal power systems studied included the oil fields of Rocky Mountain (USA) and Fort Liard (Canada). Moreover, solar thermal systems in the oil fields of Mckittrick (USA), Caolinga (USA) and Amal (Oman) were examined as applications for providing thermal energy to production facilities. From the results, this study revealed that a variety of renewable energy technologies are currently used in the oil and gas industry.

Bertsch et al., (2016) analyse the public acceptance of renewable energy and grid expansion policy in Germany using multivariate analysis of covariance (MANCOVA). The results showed that the acceptance of renewable energy sources is very high at the national level and there is also a high acceptance of grid expansion especially if it assists in increasing the share of available renewable energy sources in the system. At the local level, acceptance is mostly affected by concern about landscape modification.

Jouni K. Juntunen (2014) The sociology of consumption uses the domestication framework to examine adaptation processes in which technology becomes part of everyday life. This study applies the domestication framework to renewable decentralized energy technologies (DET). Drawing on interviews and Internet material from household and summer-cottage inhabitants using DETs in Finland, the study sheds light on how renewable energy technologies are adapted in local conditions. In such adaptation, multiple domestications are linked and lead to the increasing use of new technologies without a stable final point, a process which can be conceptualized as domestication pathways. Modularity, product multi-purposing, and convenient interoperability with other systems are key requirements to enhance the diffusion of renewable energy technologies.

Renewable energy

Renewable energy is energy derived from natural sources that are replenished at a higher rate than they are consumed. Sunlight and wind, for example, are such sources that are constantly being replenished. Renewable energy sources are plentiful and all around us. Fossil fuels - coal, oil and gas - on the other hand, are non-renewable resources that take hundreds of millions of years to form. Fossil fuels, when burned to produce energy, cause harmful greenhouse gas emissions, such as carbon dioxide. Generating renewable energy creates far lower emissions than burning fossil fuels. Transitioning from fossil fuels, which currently account for the lion's share of emissions, to renewable energy is key to addressing the climate crisis. Renewables are now cheaper in most countries, and generate three times more jobs than fossil fuels.

Current status of energy resources

Even in this 21st century, most countries still depend on fossil fuel for electricity generation, to lack of technologies, resources, and conditions to fully utilize RE to generate electricity. Nonetheless, RE-generated electricity in electric power sector is increasing rapidly nowadays due to the awareness of society towards environmental concern. The figure below presents an example of the data and analysis of fossil fuel usage, comparison of fossil fuel generation to RE generation, and trend of different types of RE usage for electricity generation. It is believed that electricity generation of residential area could be fully supplied by renewable energy in the future.

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Solar Energy

Solar energy is the most abundant of all energy resources and can even be harnessed in cloudy weather. The rate at which solar energy is intercepted by the Earth is about 10,000 times greater than the rate at which humankind consumes energy. Solar technologies can deliver heat, cooling, natural lighting, electricity, and fuels for a host of applications. Solar technologies convert sunlight into electrical energy either through photovoltaic panels or through mirrors that concentrate solar radiation. Although not all countries are equally endowed with solar energy, a significant contribution to the energy mix from direct solar energy is possible for every country. The cost of manufacturing solar panels has plummeted dramatically in the last decade, making them not only affordable but often the cheapest form of electricity. Solar panels have a lifespan of roughly 30 years, and come in variety of shades depending on the type of material used in manufacturing.

Renewable energy is healthier

According to the World Health Organization (WHO), about 99 percent of people in the world breathe air that exceeds air quality limits and threatens their health, and more than 13 million deaths around the world each year are due to avoidable environmental causes, including air pollution. The unhealthy levels of fine particulate matter and nitrogen dioxide originate mainly from the burning of fossil fuels. In 2018, air pollution from fossil fuels caused \$2.9 trillion in health and economic costs, about \$8 billion a day. Switching to clean sources of energy, such as wind and solar, thus helps address not only climate change but also air pollution and health.

Wind Energy

Wind energy harnesses the kinetic energy of moving air by using large wind turbines located on land (onshore) or in sea- or freshwater (offshore). Wind energy has been used for millennia, but onshore and offshore wind energy technologies have evolved over the last few years to maximize the electricity produced - with taller turbines and larger rotor diameters. Though average wind speeds vary considerably by location, the world's technical potential for wind energy exceeds global electricity production, and ample potential exists in most regions of the world to enable significant wind energy deployment. Many parts of the world have strong wind speeds, but the best locations for generating wind power are sometimes remote ones. Offshore wind power offers tremendous potential.

Geothermal Energy

Geothermal energy utilizes the accessible thermal energy from the Earth's interior. Heat is extracted from geothermal reservoirs using wells or other means. Reservoirs that are naturally sufficiently hot and permeable are called hydrothermal reservoirs, whereas reservoirs that are sufficiently hot but that are improved with hydraulic stimulation are called enhanced geothermal systems. Once at the surface, fluids of various temperatures can be used to generate electricity. The technology for electricity generation from hydrothermal reservoirs is mature and reliable, and has been operating for more than 100 years.

IV. RESEARCH METHODOLOGY

The first step in this bibliometric study involved systematically collecting scientific publications related to sustainable energy technologies in the field of mechanical engineering. VOSviewer was used to analyze publication trends in the field of sustainable energy technologies in mechanical engineering over the past two decades. This analysis provided insights into periods of rapid growth or decline in research output, identifying key moments and shifts in research focus. To identify dominant research themes, VOSviewer was used to extract and analyze keywords from the dataset. These scenarios provide information on PV solar cumulative installed capacity, which is used as a basis of the subsequent calculations. In the second part, the dynamic material flow model, the 100 material-energy nexus scenarios, and the assumptions made for the model parameters have been described. A co-occurrence network of keywords revealed prevalent research themes and their interconnections, providing a comprehensive overview of the research areas in sustainable energy technologies in mechanical engineering. In addition, it describes the main parameters used in the model including the sub-technologies MS, their MC, and their LT. It also describes the basis of the evaluation of 10 GES in terms of production capacity and resources availability. The third part describes metals coproduction and the

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basis of the estimates of the host metals production as a result of the companion metals demand, which is also used in the evaluation of GES.

V. RESULTS AND DISCUSSIONS

These clusters offer an organized perspective of the various study topics in mechanical engineering's field of sustainable energy technology. Alternative fuels, renewable energy sources, grid modernization, emissions reduction, hydrogen use, and overall sustainable energy technology are just a few of the topics that each cluster focuses on. In addition to highlighting the current trends and directions that academics are investigating to address the global challenge of sustainable energy and environmental conservation, the keywords within each cluster emphasize the multidisciplinary nature of study in this topic.

Table 1: Cluster Identity

Cluster	Total Items	Most frequent keywords (occurrences)	Keyword
1	15	Biogas (25), electric vehicle (20), sustainability (20), water (15)	Alternative fuel, battery, biogas, clean energy, current trend, electric vehicle, green energy, increase, industry, oil, power source, strategy, sustainability, sustainable development, water.
2	15	clean energy technology(25), power electronic (30), renewable energy resource (20)	Biomass, clean energy source, clean energy technology, energy production, environmental energy, global trend, hydropower, power electronic, power generation, renewable energy resource, renewable energy system, utilization, way, Wind energy
3	8	Microgrid(20),power system(25),smart grid(15)	Grid, integration, micro-grid, new trend, penetration, power system, recent trend, Smart grid
4	8	Emission (20), non renewable energy system (15), wind turbine(20)	Emission, energy consumption, non renewable energy system, progress, state, wind energy technology, wind turbine, world
5	7	Hydroge (20), sustainable energy source(30)	Biofuel, future prospect, hydrogen, market trend, production, sustainable energy source, vehicle
6	5	Sustainable energy technology (20)	Energy efficiency, energy storage, engineering, mechanical engineering, sustainable energy technology

Electric cars and alternative fuels are the main subjects of Cluster 1, as they are essential to the development of sustainable energy and transportation systems. The term "biogas," which is a renewable substitute for conventional fuels, is used frequently to highlight the significance of sustainable fuel sources. An alternative to more environmentally friendly transportation is represented by electric cars. Water and sustainability are also important

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buzzwords that draw attention to the environmental aspects of this cluster. Renewable energy sources and clean energy technology are the focus of Cluster 2.

Table 2: Citations Analysis

Citations	Authors and year	Title
8884	SChu, A Majumdar (2012)	Opportunities and challenges for a sustainable energy Future
5732	B Scrosati, J Garche (2010)	Lithium batteries: Status prospects and future
4984	JM Carrasco, LG Franquelo (2006)	Power-electronic systems for the grid integration of Renewable energy sources: A survey
3808	NL Panwar, SC Kaushik, SKothari (2011)	Role of renewable energy sources in environmental protection: A review
3158	DEOlivares, AMehrizi-Sani (2014)	Trends in micro-grid control
2950	OEllabban, HAbu-Rub, FBlaabjerg (2014)	Renewable energy resources: Current status, future Prospects and their enabling technology

These highly study collectively represent a diverse range of topics within the field of sustainable energy technologies in mechanical engineering.

Table 3: Keywords Analysis

Most occurrences		Fewer occurrences	
Occurrences	Term	Occurrences	Term
57	Production	15	Wind energy technology
57	Integration	15	Oil
51	Recent trend	15	Nonrenewable energy source
50	Mechanical engineering	15	Water
49	Current trend	14	Clean energy technology
44	Wind energy	14	Hydropower
39	Power generation	13	Market trend
38	Energy storage	13	Biofuel
37	State	12	New trend
37	Grid	11	Geothermak energy
34	Utilization	11	Biogas
33	Renewable energy system	11	Alternative fuel
33	Emission	11	Green energy
31	Industry	11	Smart grid
31	Power system	11	Clean energy source

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They serve as foundational references, offering insights into critical aspects such as environmental impact, energy storage, grid integration, and the future of sustainable energy. Researchers and policymakers continue to draw upon these works to inform their efforts to advance sustainable energy solutions.

VI. CONCLUSION

The return-to-renewables will help mitigate climate change is an excellent way but needs to be sustainable in order to ensure a sustainable future for generations to meet their energy needs. The area has expanded and changed significantly, with an increasing focus on innovation, interdisciplinary cooperation, and sustainability. The study's conclusions are a useful tool for practitioners, politicians, and scholars alike. They underline the significance of continuing to invest in sustainable energy solutions, offer direction for future research, and inform strategic alliances. The foundation for furthering the shift to greener, more efficient, and ecologically conscious energy systems is provided by this research. A sustainable and successful energy future can be paved by stakeholders working together to leverage the lessons gained from this study. The energy transition is a multifaceted issue. Energy is a requirement in our everyday life as a way of improving human development leading to economic growth and productivity. Knowledge regarding the interrelations between sustainable development and renewable energy in particular is still limited. The study brought to light the opportunities associated with renewable energy sources; energy security, energy access, social and economic development and climate change mitigation and reduction of environmental and health impacts. There are challenges that tend to hinder the sustainability of renewable energy sources and its ability to mitigate climate change.

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