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Comparative Insights on Sustainable Manufacturing Systems for Energy Efficiency in Nigeria

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Abstract: *In order to fill in the gaps in empirical data and situational integration of sustainable manufacturing systems, this study compiles research on the following topics: energy efficiency, the impact of technology transfer on local industries, local design strategy adaptation, and a comparative analysis with other developing economies. This was accomplished by carrying out a methodical evaluation of peer-reviewed publications that applied quantitative modeling, case studies, and policy analysis to the manufacturing and energy sectors in Nigeria as a developing nation. It has been discovered that passive design and the integration of renewable sources can achieve an energy efficiency of 20–25%; however, the process is impeded by the legislative and infrastructure backlog. The financial, institutional, and sociocultural barriers that impede local innovations and industrial development continue to impede technology transfer procedures. Though they are not entirely relevant in settings related to manufacturing, locally adapted design methods are successful in co-creating strategies in the facilitation of building and rural energy systems. It will be challenging for Nigeria to directly adopt foreign models due to comparative evaluations that have identified Nigeria's policies as inconsistent and its infrastructure as inadequate when compared to peers. Understanding the significance of integrated and context-sensitive solutions which must be created to assist connect technical innovation with socio-political contexts is made easier by conceptualizing the findings. Nigeria and other developing nations apply the findings to enhance sustainable manufacturing systems through policy development, industrial policy, and scholarly discourse.*

Keywords: Hardwood, Softwood, Fast Pyrolysis, Bio-oil, Sawdust

INTRODUCTION

Given Nigeria's challenges with energy scarcity, urban sprawl, and sustainable economic growth, research on sustainable manufacturing systems in the nation has become crucial (Avwioroko, 2023; Ugwoke *et al.,* 2024). Over the past several decades, Nigeria's energy sector has evolved, with a shift away from gas and oil to renewable energy and local energy efficiency initiatives (Chanchangi *et al.,* 2022; Adeyemi-Kayode et al., 2022). With a population of over 200 million, Nigeria is the largest country in Africa. It also faces a severe energy crisis, with just 40 to 45 percent of the population having a reliable supply of electricity (Adeyemi-Kayode *et al.,* 2022; Stephanie *et al.,* 2024). This makes the transition crucial. The need to advance the concept of sustainable manufacturing processes and energy systems is even more important given the socioeconomic effects of energy poverty, which include problems like low industrial output and underdevelopment of rural areas (Abe *et al.,* 2024)

(Oyedepo, 2013). Nevertheless, Nigeria continues to struggle to realize sustainable manufacturing and energy efficiency despite policies and other efforts along with sufficient renewable energy resources (Nitte & Salahudeen, 2023; Yekini *et al.*, 2024). The knowledge gap is what the transfer of technology means to local industries, the extent to which design approaches can be adapted to local applications and the difference between Nigerian sustainable manufacturing and the manufacturing of other developing economies (Akinwale, 2018; Aderemi *et al.*, 2022; Mandal *et al.*, 2024). Whereas one of the studies addresses the possibility of renewable energy and energy management systems (Victor *et al.*, 2024), the other one focuses on obstacles like infrastructural barriers, policy mismatch, and sociotechnical challenges (Sadiq, 2020; Abdullahi *et al.*, 2021). There are also controversies about how well the current policies are working and how quickly technology needs to be adopted, and some are more about decentralization and community-based solutions (Pereira, 2022), whereas others revolve around massive improvement of the grid (Pavanelli *et al*., 2023), the Burden of the Broken Grid (Modelling, 2023). The implications of such gaps are further energy inefficiency, more environment degradation, and failed industrial competitiveness (Adom & Adams, 2018; Aderemi *et al.*, 2022).

The idea behind the conceptualization of such review is the synthesis of sustainable manufacturing, energy efficiency, and technology transfer with reference to the Nigerian situation (Olayinka, 2012; Mandal *et al.*, 2024). Sustainable manufacturing can be described as a production of products by cost-effective methods that will reduce the negative adverse effects on the environment with minimal energy and resources used (Mandal *et al.*, 2024). Energy efficiency means improving the use of energy in order to produce wanted results with the least amount of wastage (Olayinka, 2012). Technology transfer can incorporate the idea of innovations to benefit a certain industry through localization to improve its productivity and sustainability (Akinwale, 2018). The concepts are interconnected and effective transfer of technology can enhance energy efficiency and sustainable manufacturing results, and this is the basis of the focus of this study. This systematic review aims to have a critical view of the sustainable manufacturing system status in Nigeria with respect to design strategies adaptation, energy efficiency of the manufacturing system, and how the transfer of technology affected the local industries. It wants to give a comparative analysis with other developing economies to come up with the best practices and policy recommendations. The value of the review lies in the integration of different research strands in a bid to fill the identified gaps and to provide stakeholders with information on how to achieve a sustainable industrial practice in Nigeria (Adeshina *et al.*, 2024; Mandal *et al.*, 2024). Such review adapts the methodology of systematic search and appraisal, and utilizes both empirical and theoretical reports retrieved via various databases and dating back to the previous two decades. Studies conducted on sustainable manufacturing, efficiency in energy, and technology transfers in Nigeria and similar developing settings are the areas of inclusion criteria. Multi-criteria decision-making and policy analysis are analytical frameworks in which to report findings. The review has been organized in a way that it introduces the energy, manufacturing landscape, then the impacts of technology transfer, the adaptations of the design, and the evaluative knowledge through comparative knowledge, and finally the strategic suggestions (Adeyemi-Kayode *et al.*, 2022; Nitte & Salahudeen, 2023; Mandal *et al.*, 2024).

MATERIALS AND METHODS

The present systematic review used a thorough literature search and evaluation procedure to analyse sustainable manufacturing systems in Nigeria in time and analysis of energy efficiency, technology transfer, local design adaptations and comparative studies with other developing countries also. The research question was then methodically shaped into various specific search questions in a bid to cover the entire topic area of interest which here would be community involvement, local resources usage and the socio-economic effects in sustainable manufacturing situations. The search of a variety of academic databases covering more than twenty years took place, and the inclusion criteria were aimed at including studies dealing with sustainable manufacturing, energy efficiency, and technology transfer in Nigeria and other analogous developing environments. A total of 52 papers were retrieved in the initial search but this was widened to 163 candidate papers via backward and forward citation chaining. Forward and backward citation chaining involved analysing reference lists of key works to uncover earlier work, and forward citation chaining tracing newer works citing key works to discover the emerging issues and methodological developments. The collected pool of 163 candidate papers was processed with relevance scoring and sorting method to determine the actual 158 relevant candidate papers that were finally analyzed in detail by the relevance scores of creating 50 highly relevant papers. To explicitly cover the aims of the research the analytical framework adapted the methods of multi-criteria decision-making, and policy analysis in terms of which findings are organized in terms of energy efficiency indicators, effect on technology transfer, effectiveness of design adaptation, relative sustainability results, and policy outcomes.

RESULTS AND DISCUSSION

3.1 Energy Efficiency Achievements and Potential

The discussion indicates that there is significant evidence to prove that massive energy savings are possible through the numerous sustainable production methods present in Nigeria. Retrofits of building envelopes and passive design measures are proven to result in energy savings of 20-21 percent (Ugwoke *et al.,* 2024), and residential archetypes in 20-25 percent savings potential when using bottom-up modeling (Nwagwu *et al.,* 2024). The research findings are also of specific interest to the manufacturing sector in Nigeria due to its building envelope and thermal energy insulation approaches based on adaptability to local climatic conditions, which can serve as a gateway to energy savings in the sector (Combining Building Simulation and Sensit, 2023). This study confirms the idea that hybrid renewable energy systems and mini-grids are demonstrating high efficiency in rural electrification applications (Oyedepo *et al.,* 2019; Nana and Dioha, 2024; Ozue *et al.,* 2025), and that energy management systems and efficiency initiatives determined by policy are important in scaling energy savings in manufacturing and building industries (Olayinka, 2012; Tunji-Olayeni *et al.,* 2020; Victor *et al.,* 2024). Nevertheless, the literature also demonstrates ongoing resistance as energy inefficiency is still associated with systemic barriers, which include grid unreliability and institutional shortcomings (Adom & Adams, 2018; The Burden of the Broken Grid: Modelling, 2023), which persistently weaken the feasibility of applying the concept of energy efficiency into the practice and by extension, the Nigerian industries.

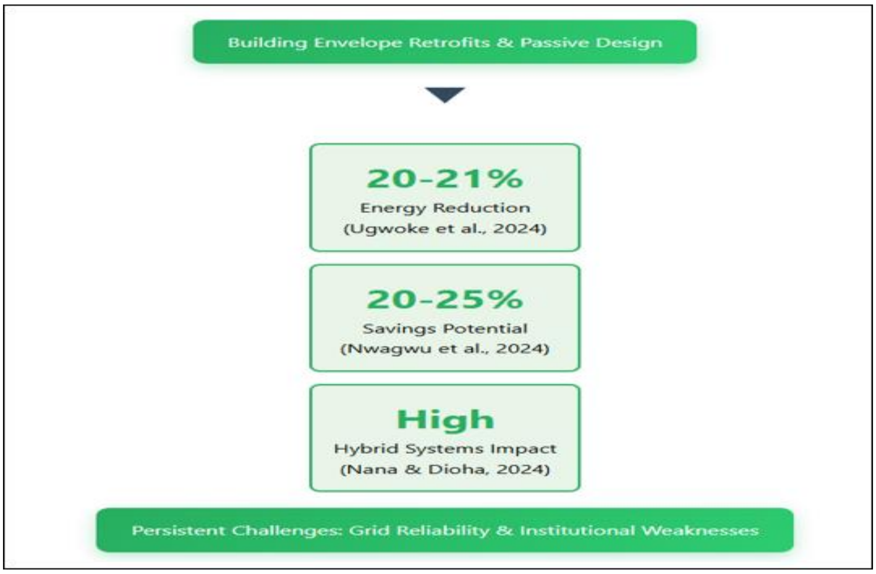

Fig. 1 Energy efficiency achievements and potential

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The assessment of industrial energy efficiency has also shown renewable energy application to be able to diversify energy supply and increase overall system efficiency (Avwioroko, 2023), and energy transition plans that aim to integrate renewables provide the opportunity to increase efficiency in manufacturing (Ekpotu *et al.,* 2024). According to the studies, mini-grids decrease the dependence on the exploitation of fossil fuels and lead to the implementation of more efficient system's operating (Nana & Dioha, 2024), the utilization of the rural materials promotes the efficiency of energy in the decentralized system (Jia, 2024). It is also important to note that renewable integration increases the energy efficiency and access (Adeshina *et al.,* 2024), and renewable energies are shown to increase energy governance and efficiency outcomes (Umeh *et al.,* 2024). In addition, benchmarking indicates that the automobile industries are the most sustainable in manufacturing activities (Mandal *et al.,* 2024), and passive design help to curtail 20-21 percent of the residential energy use by reducing it (Combining Building Simulation and Sensit, 2023). The cost cut solutions enhance clean energy efficiency (Ekung *et al.,* 2020), and in the agricultural sector, hybrid systems minimize energy expenses and emission (Emezirinwune *et al.,* 2024). Clean energy, in turn, can provide efficiency benefits in both rural regions (Yekini *et al.,* 2024) and renewable integration to enhance energy efficiency in urban (Abe *et al.,* 2024) as well as rural areas (Yekini *et al.,* 2024).

3.2 Technology Transfer Impacts and Barriers

The literature paints a multifaceted picture, where there is no characteristic way of succeeding in technology transfer in the manufacturing sector in Nigeria. The effectiveness of technology transfer also differs significantly among the sectors such as, automobile manufacturing can be considered as a point of reference when doing comparative research in India, but in Nigerian industries, adoption and innovation capabilities are much more problematic (Aderemi *et al.,* 2022; Mandal et al., 2024). According to the research, the barriers of financial, policy and socio-cultural nature usually limit local innovation and uptake of renewable energy technology transfer (Abdullahi *et al.,* 2021; Avwioroko, 2023). The importance of local ownership and participation in community-based and decentralized models used in various studies is a critical finding that consumes the necessity of better technology transfer since adoption of successful technologies is beyond mere importation of the foreign technologies (Sadiq, 2020; Jia, 2024). Discussing the analysis, it can be highlighted that the policy reform and the carbon pricing mechanism are becoming the ways to stimulate the adoption of technologies in energy-intensive sectors (Nwokolo *et al.,* 2023; Ayodele *et al.,* 2024) which means that there are already changes in terms of the struggles to overcome traditional obstacles. The manufacturing industry is hard hit by specific challenges evidenced by literature that indicates limited effect of technology transfer on manufacturing value addition and industrial growth (Aderemi *et al.,* 2022). Both policy reforms and partnerships in technology transfer look promising (Avwioroko, 2023), and attention to grid and storage technology improvement is minimal (Ekpotu *et al.,* 2024). Additionally, the choices on technological integration in mini-grids contribute to the regional innovation (Nana & Dioha, 2024), and the community engagement contributes to the technology acceptation and adaptability (Jia, 2024). The study has uniformly found that policy reform encourages the use of technology and innovation (Adeshina *et al.,* 2024), and the development of solar, wind, and biomass technology have received great attention in several studies (Umeh *et al.,* 2024).

A number of reports indicate that the subject of technological transfer is diverse. The limitations of technology transfer are connected to the gaps in supply chain and research and development (Ekung *et al.,* 2020), whereas solar energy implementation is associated with technical inefficiencies (Abdullahi *et al.,* 2021). The systemic challenges are a limitation to technology transfer (Ndukwu *et al.,* 2021), and the capacity of low-carbon innovation is so poor in institutional terms (Akinwale, 2018). Furthermore, transfer of the technology has gaps concerning knowledge transfer (Onah *et al.,* 2021) regarding the applications of technology in the agricultural sector and industrial energy efficiency has drawbacks with grid reliability (Oyedepo, 2013).

3.3 Local Adaptation of Design Strategies

The literature shows mixed success with design strategy adaptation to local Nigerian conditions with the greatest success in certain industry sectors but lacking complete manufacturing applications. The influence of locating design strategies in the specifics of Nigerian locale is traced in building typologies, passive design, and the structures of hybrid systems (Combining Building Simulation and Sensit, 2023; Ugwoke *et al.,* 2024; Nwagwu *et al.,* 2024). The study reveals that there are agricultural and rural energy systems that exhibit localised design solutions that combine local materials and the local needs (Onah *et al.,* 2021; Emezirinwune *et al.,* 2024). Nonetheless, there are major discrepancies in applications in manufacturing. There are no concentrative studies of design adaptation in some fields, so there is a gap in the research on the industry in regard to concentration on the industries in relation to design modifications (Aderemi *et al.,* 2022; Mandal *et al.,* 2024). Local context has the pivotal role, with socio-technical and cultural conditions having a major impact on design adaptation success in community energy programs (Sadiq, 2020). The discussion shows that adaptations that succeed in most cases involve utilization of local materials and involvement of the communities. Decentralized systems focus on the use of local materials and locally driven design and policy frameworks are interfaced with the Nigerian context (Umeh *et al.,* 2024). Literature proves that islanded systems are configured to rural Nigerian conditions (Ozue *et al.,* 2025), designed according to the needs of energy in the agricultural sector (Emezirinwune *et al.,* 2024), and an understanding of user-centered, contextual designing approaches is promoted (Nitte & Salahudeen, 2023). It is important to note that the adaption of hybrid power systems occurs both locally (Abe et al., 2024), and that of design currently has challenges associated with economic viability (Adebanji *et al.,* 2024) and climate of various regions in Nigeria (Ndiwe *et al.,* 2023). Further findings indicate the thermal insulation and the so-called traditional envelopes are oriented to local conditions (Combining Building Simulation and Sensit, 2023), whereas standardization and design should be standardized to work more efficiently (Ekung *et al.,* 2020). Socio-cultural aspects are a problem of local adaptation (Abdullahi et al., 2021), and energy planning relies on community-level adaptation (Pereira, 2022). Energy efficiency and material reuse are included in the sphere of design practices (Tunji-Olayeni *et al.,* 2020), and design corresponds with the objectives of sustainable development (Oguntuase & Windapo, 2021).

3.4 Comparative Sustainability Outcomes

Nigeria has an opportunity to follow the example of developing economies as the comparative analysis carried out in Fig. 2 demonstrates both opportunities and challenges that lie in benchmarking its progress against other developing economies. Nigerian research compares the sustainability outcomes to the globally established emission targets, emission net-zero emission-zero goals, and developing country contexts (Nwagwu *et al.,* 2024; Ekpotu *et al.,* 2024; Adeshina *et al.,* 2024). The study indicates that the integration of renewable energy has similar environmental and economic impacts as the rest of the developing economies, but social impacts are highly differentiated (Umeh *et al.,* 2024; Pereira, 2022; Ugwoke *et al.,* 2021).

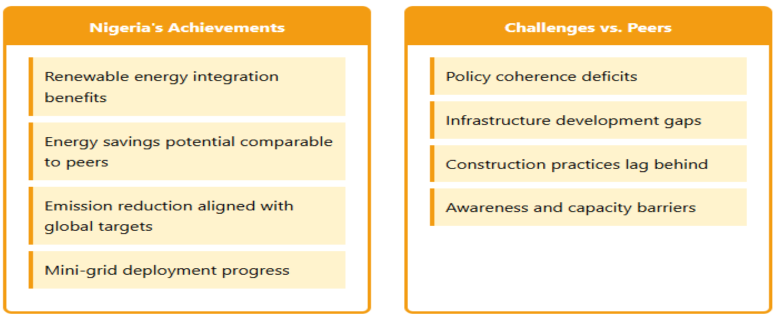

Fig. 2 Comparative sustainability outcomes

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There are critical issues of coherence and infrastructure developments prevalent in policy matters. Nigeria has weaknesses in its policy consistency and infrastructure when compared to peers (Nwaneto *et al.*, 2018; Nitte & Salahudeen, 2023) and the practice of sustainability in construction and industry within Nigeria is below the desired mark because of constraints in knowledge and competence (Tunji-Olayeni *et al.*, 2020; Omopariola *et al.*, 2022). The analysis repeatedly indicates that the potential to save energy can be used in other developing nations (Ugwoke *et al.*, 2024), and the scenarios of emission reduction making a reference to the international goals (Nwagwu *et al.*, 2024). The global comparisons show the learning possibilities and implementation difficulties. Sustainability rating of industries reveals the experience of other developing countries as opportunities in renewable upscaling (Avwioroko, 2023; Mandal *et al.*, 2024), whereas the reduction of emissions is in net-zero objectives (Ekpotu *et al.*, 2024). The study suggests that efficiency gains of the market are competitive with their peers (Victor *et al.*, 2024) and mini-grid installation can compare to those of the net-zero world (Nana & Dioha, 2024). But when analyzing rural energy strategies against international decentralized systems of energy, there is a difference in motion in terms of policy analysis regarding other developing nations (Pereira, 2022; Jia, 2024). There are certain comparative results which show that performance is different in each sector. Global benchmarking of environmental and economic benefits is done (Umeh *et al.*, 2024) and rural electrification is juxtaposed with other developing situations (Olaniyan *et al.*, 2024). The agricultural energy systems are benchmarked to the objectives of rural development (Emezirinwune *et al.*, 2024), and there is ambiguous success in comparative technical and economic studies (Adebanji *et al.*, 2021). The comparison of solar potential is made to other developing nations (Chanchangi *et al.*, 2022), and sustainability standards are used globally (Asime, 2022).

3.5 Policy and Socio-Economic Influences

The economic and social evidence-based findings indicate the policy frameworks and the issues of socio-economic factors as a severe determinant of sustainable manufacturing success in Nigeria as portrayed in Fig. 3.

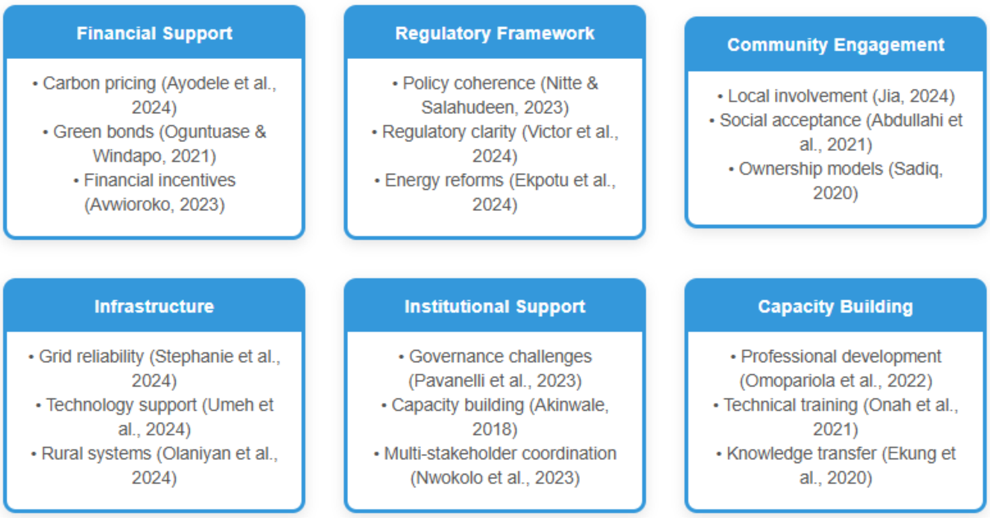

Fig. 3 Policy and socio-economic influences

In the literature of the future, both policy frameworks and financial incentive and regulatory clarity have been noted as vital enablers or inhibitors of sustainable manufacturing and energy efficiency repeatedly (Avwioroko, 2023; Victor *et al.*, 2024; Umeh *et al.*, 2024). All trials reveal that both social and cultural aspects and community action influence the process of implementing technology to a significant degree, implying the adoption and the possibility of employing sustainable practices (Sadiq, 2020; Abdullahi et al., 2021; Jia, 2024).

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Institutional forces are especially effective, and institutional history and dynamics of governance have arguably presented everyday forces that influence the way forward with regard to energy transition and the effectiveness of policies (Pavanelli *et al.,* 2023). The literature promotes holistic measures, where a multi-faceted policy involving regulation, incentive, education and partnership between the state and private business is promoted to enhance sustainability (Ekung *et al.,* 2020; Nitte & Salahudeen, 2023; Nwokolo *et al.,* 2023). The research works show certain policy requirements in various spheres. Green energy rehabilitation requires policy mix (Ugwoke *et al.,* 2024) and green energy policy needs shifts in materials and decarbonization of grids (Nwagwu *et al.,* 2024). Moreover, such barriers are policy, financing, infrastructure, and capacity concerns (Avwioroko, 2023), whereas financial support and infrastructure play a significant role in terms of transition success (Ekpotu *et al.,* 2024). The study highlights that there is a critical need to implement the reforms and remove impediments by decision-makers (Victor *et al.,* 2024). The policy, regulatory, and financial determinants have been identified as critical success factors (Nana & Dioha, 2024). Other policy implications will arise in the different studies. Community participation in the early stages is crucial to policy success (Jia, 2024), whereas barriers should be defeated with the teamwork of the state and non-governmental organizations (Adeshina *et al.,* 2024). Regulatory frameworks and incentives are helpful in adoption (Umeh *et al.,* 2024) and policy assistance is necessary with scaling reuse systems (Olaniyan *et al.,* 2024). The directions in research focus on policy and infrastructure requirements (Ozueee *et al.,* 2025), whereas policy and data hurdles are factors that limit the broader adoption (Emezirinwunees *et al.,* 2024).

3.6 Sectoral Analysis and Performance Variations

The literature indicates that there is a great variance in the implementation of sustainable manufacturing and performance between the various industries in the economy of Nigeria as indicated in Fig. 4.

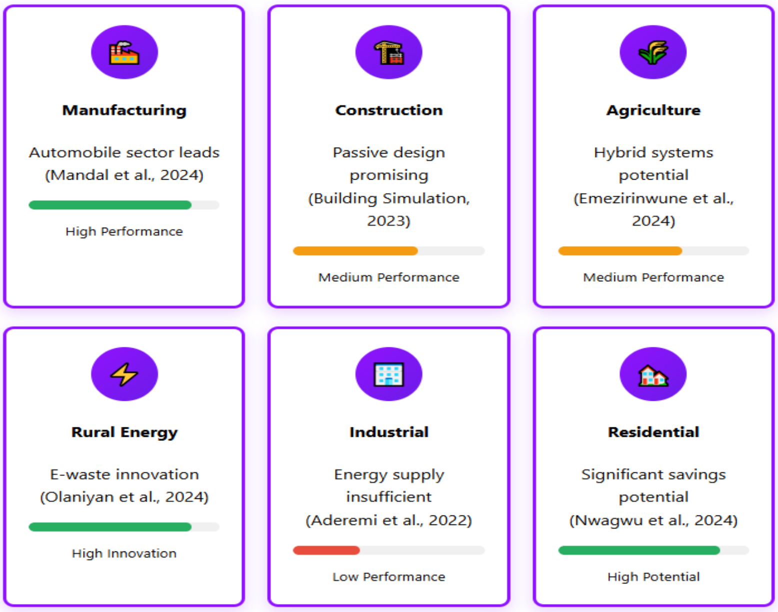

Fig. 4 Sectoral analysis and performance variations

These results can be used in industry benchmarking to reveal that the automobile sector has the highest rate of sustainable manufacturing practices (Mandal *et al.,* 2024), and in residential archetypes to show high potential of energy savings (Nwagwu *et al.,* 2024). The construction sector has a lot of potential, as passive design can decrease energy usage in houses by 20-21 percent (Combining Building Simulation and Sensit., 2023), and cost minimization strategies increase the efficiency of clean energy (Ekung *et al.,* 2020).

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There are special possibilities and difficulties in agricultural use. The hybrid systems are energy-efficient and decrease energy expenditure and emissions in farming (Emezirinwune *et al.,* 2024). At the same time, renewable energy devices enhance energy efficiency in agriculture (Onah *et al.,* 2021). Nevertheless, there is impending implementation, with solar energy implementation crippled by technical inefficiencies (Abdullahi *et al.,* 2021), and technology transfer held back by a financial and social barrier (Abdullahi *et al.,* 2021). The rural electrification sector is shown to have advanced in terms of the innovative approach. Reduction in reuse of e-waste components enhances rural energy efficiency (Olaniyan *et al.,* 2024), and optimization in the use of hybrid renewable energy systems enhances rural energy efficiency (Ozue *et al.,* 2025). There are a combine set of mixed results in manufacturing industries where the current supply of clean energy is not nearly enough to reach industrial efficiency at present (Aderemi *et al.,* 2022), and energy inefficiency remains because of systematic problems (Adom & Adams, 2018). The promising developments can be traced in building and construction sectors. The green buildings enhance energy efficiency and sustainable construction practices increase energy efficiency (Tunji-Olayeni *et al.,* 2020; Oguntuase & Windapo, 2021). SEI energy planning reduces inefficiency in the rural areas (Ugwoke *et al.,* 2021), efficient energy management can allow industrial processes to achieve efficiency (Oyedepo, 2013). The community energy systems advance local energy efficiency (Sadiq, 2020), and the dynamics in institutions influence energy efficiency transitions (Pavanelli *et al.,* 2023).

3.7 Barriers and Implementation Challenges

The study has pointed continuously and repeatedly to several inter-related obstacles on the way to a large scale adoption of sustainable manufacturing practices in Nigeria. Financial capabilities are revealed as one of the main barriers, and solar photovoltaic economic feasibility is constrained by excessive prices (Adebanji *et al.,* 2024), whereas the problem of impacting technology is a lack of finance and awareness (Ndiwe *et al.,* 2023). The existence of these financial obstacles is further coupled with regulatory and institutional barriers since technology transfer is hampered by the lack of supply chains and research and development (Ekung *et al.,* 2020), and the constraints in the implementation of solar energy are the technical ineffectiveness (Abdullahi *et al.,* 2021). There are infrastructural shortcomings that cause further problems in various sectors. Technology transfer is a problem with stand-alone microgrids because of obstacles to security and management (Stephanie *et al.,* 2024), whereas efficiency is affected by energy deficit in different sectors (Ndukwu *et al.,* 2021). It emerges that systemic issues pose a barrier to technology transfer (Ndukwu *et al.,* 2021) and low-carbon innovation capacity is not high because institutional factors limit it (Akinwale, 2018). The issues concerning capacity and issues of awareness further retard progress. The knowledge gap in the agricultural usage of technology curbs technology transfer, and the energy efficiency of industries is constrained by the system security and the reliability of the grid (Oyedepo, 2013; Onah *et al.,* 2021). The study reveals that there are constraints in sustainable construction practice imposed by professional capacity, whereas technology transfer has its ways through the client demand and corporate social responsibility and experiences implementation barriers (Tunji-Olayeni *et al.,* 2020; Omopariola *et al.,* 2022). These are coupled with market and regulatory barriers. Tariff systems and subsidy systems affect technology transfer whereas the issue of energy inefficiency is undermined by institutional and market failures (Adom & Adams, 2018). Challenges that were outlined include policy and regulatory issues in a range of areas, and social norms and intermediaries affect the adoption behavior (Nitte & Salahudeen, 2023). Enhancement of technology utilisation is hindered by barriers to investment (Yekini *et al.,* 2024), and the technology adoption method is barred by barriers to finance (Adebanji et al., 2024).

3.8 Emerging Trends and Innovation Pathways

There are various emerging trends that the literature points to as the presence of opportunities to propel sustainable manufacturing in Nigeria. A major opportunity like decitralized energy systems, where community energy systems enhance local energy efficiency (Sadiq, 2020) and where decentralized energy systems enhance efficiency and sustainability via community choice aggregation models (Asime, 2022).

The convergence between digital solutions and advanced modeling practices also holds promise, and the rise of energy management systems in the market can potentially boost efficiency in the field (Victor *et al.,* 2024) whereas better availability of power plants also translates into greater energy efficiency (The Burden of the Broken Grid: Modelling, 2023). The policy into the market based instruments like carbon pricing comes up as innovative. Carbon pricing is used to promote energy efficiency in the industry (Ayodele *et al.,* 2024), and an increase in the capacity of renewable energy helps to support energy efficiency used as a policy and regulatory tool (Nwokolo *et al.,* 2023). The study shows that there is an increase in awareness of combined strategies, where clean energy technologies can ensure efficiency in rural markets (Yekini *et al.,* 2024), and renewable integration is the most efficient element of energy in urban and rural sites (Abe *et al.,* 2024). Sustainable manufacturing is promising in terms of community-driven innovation pathways to development. It is the presence of community input and local resources that take the sustainable manufacturing systems one step forward, with the opportunities of developing energy efficiency and adaptation of technology focused on (Jia, 2024).

The researches indicate that the community energy projects promote not only technological development and responsive local design (Sadiq, 2020) but also use of local resources and issue of socio-economic implications (Jia, 2024). Sophisticated new modeling and analytical techniques are becoming evident. The scenario analysis demonstrates that renewables enhance energy efficiency (Adeyemi-Kayode *et al.,* 2022) and that frugal innovation introduces technology to the country-side (Olaniyan *et al.,* 2024). The combination of solar, wind, hydro, and biomass technology promises better integration (Ozue *et al.,* 2025), whereas green bonds investment promotes the technology transfer (Oguntuase & Windapo, 2021). Market and regulatory obstructions are addressed by policy solutions (Chanchangi *et al.,* 2022), and the perception of the efficiency of energy resources differs by type of resource (Raimi & Olowo, 2022). New sectoral innovations are also presented in the research. Innovation on technology promotes the adaptation of solar energy (Ojo *et al.,* 2023), and transfer of technology differs depending on the kind of system, as well as location (Adebanji *et al.,* 2021). Technology transfer is helped by the community ownership models (Sadiq, 2020), the historical governance patterns alter the technology transfer (Pavanelli *et al.,* 2023). The modeling of technology transfer is done through scenarios based methods (Adeyemi-Kayode *et al.,* 2022), and this illustrates how methods of analysis in the field have developed over time.

The results of the present systematic review identify a very nuanced picture of sustainable manufacturing systems in Nigeria, which includes impressive potential and constantly occurring implementation issues. The technical possibility of sustainable manufacturing practices is demonstrated by the documented energy efficiency savings of 20-25 percent via passive design and integration of renewables (Ugwoke *et al.,* 2024; Nwagwu *et al.,* 2024) but the more important question of how to practically achieve these benefits is subject to a variety of multidimensional barriers, which lies beyond the technological scope and touch on institutional, financial, and socio-cultural factors. The situation of technology transfer has a rather complex character, with the standard performance of the automobile industry well highlighted (Mandal *et al.,* 2024) and the unimpressive results noted on the issues of manufacturing value addition in the Nigerian industries (Aderemi *et al.,* 2022). This gap is the highlight of the essentiality of contextual adaptation as opposed to blind and mass adoption of technology. The effectiveness of community-based and decentralized models in promoting technology transfer (Jia, 2024; Sadiq, 2020) implies that the local ownership and participation are essential prerequisites of successful technology integration in violation of the top-down policy regarding the promotion and use of technology in the industrial development. The fact that carbon pricing mechanisms and policy reforms have become tools of giving incentives towards the adoption of technologies (Ayodele *et al.,* 2024; Nwokolo *et al.,* 2023) may point out to how the policies are evolving to remember of market-based solutions as well as regulatory actions. The localization of the design strategy presents both the opportunities and the lack thereof in the sustainable manufacturing development of Nigeria.

Where fabrication of typologies and agricultural energy systems indicates effective localization of their resources and a consideration of community demand (Emezirinwune *et al.,* 2024; Onah *et al.,* 2021), there is little evidence that the manufacturing sector has systematically adjusted to its design (Mandal *et al.,* 2024; Aderemi *et al.,* 2022). This research gap constitutes a highly important domain between research and practice as design changes tailored to manufacturing practices may have a considerable positive impact on the sustainability results and competitiveness of industry. Conclusions on the socio-technical and cultural determinants of the successful adaptation of design (Sadiq, 2020) confirm the relevance of participatory methods based on the local approach rather than technical requirements. Comparison studies with other developing economies can give light to the similar challenges and peculiar opportunities in the Nigerian sustainable manufacturing development path. Although Nigeria is in a similar position to its peers in the integration of renewable energy (Umeh *et al.,* 2024; Pereira, 2022), policy deficit in coherence and lack of infrastructural ability vis-a-vis its peer countries (Nwaneto *et al.,* 2018; Nitte & Salahudeen, 2023) evidence the flaws in the system, which only a full-blown reform agenda can address. The delayed trend in construction and industrial sustainability practices, as presented due to awareness and capacity barriers (Tunji-Olayeni *et al.,* 2020; Omopariola *et al.,* 2022), outlines the human capital aspects of the sustainable manufacturing development process, where technical solutions have to be supplemented with the capacity building and institutional strengthening projects.

The sectoral analysis shows huge differences in performance that indicate the pattern of differing adoption within the economy of Nigeria. The dominance of the automobile industry in sustainable manufacturing (Mandal *et al.,* 2024) compared to the lack of clean energy to serve the rest of the industrial efficiency (Aderemi *et al.,* 2022) suggests unequal rates of development that can contradict industrial equality. The potential of leapfrogging technologies to overcome the issue of energy access due to the promising advances in rural electrification research on e-waste innovation (Olaniyan et al., 2024) and hybrid renewable systems (Ozue *et al.,* 2025) implies that the value of hybrid systems will go beyond manufacturing interests or the opportunity to save residential archetypes in large quantities (Nwagwu *et al.,* 2024). The fact that the implementation barriers that exist in Nigeria in the financial, infrastructural, institutional and regulatory domains is indicative of the systematic nature of limitations encountered in sustainable manufacturing in Nigeria. The capacity of solar photovoltaic to become adopted (Adebanji *et al.,* 2024), lack of reliability that grid connection introduces to a microgrid (Stephanie *et al.,* 2024), and constraints to innovation imposed by the institutional factors (Akinwale, 2018) altogether determine the difficult operating environment necessitating the concerted efforts to mitigate the impacts of the mentioned phenomena. The fact that key success drivers such as market failures and regulatory challenges have been identified (Adom & Adams, 2018), indicates that sustainability manufacturing development cannot solely lean on technological innovations, but has to consider wider governance as well as market structuring concerns.

Something new that is growing is the direction of decentralized energy systems, novel modeling strategies and even community based innovation pathways which can provide fertile ground in the progress of manufacturing towards sustainability. The achievements of community energy systems in enhancing area efficiency (Sadiq, 2020) and the increasing awareness of potential of energy management systems (Victor et al., 2024) point to regional changes that allow incorporating technology innovation with social engagement. The case of the emergence of scenario analysis strategies to renewable integration (Adeyemi-Kayode *et al.,* 2022) and frugal innovation to rural activities (Olaniyan *et al.,* 2024) shows the evolution of an analytical tool base that may inform rational decision-making. The policy and socio-economic factors that have been proposed by different studies are always keen on the fact that institutional frameworks are significant to the attainment of sustainable manufacturing results. The recurrent discussions on policy architecture, monetary grants, and the existence of regulatory transparency as the factors of facilitating and limiting appear critical of the quality of governance in long-term pathways of developing sustainably (Avwioroko, 2023; Victor *et al.,* 2024; Umeh *et al.,* 2024).

The social embeddedness of changes in technology (Abdullahi *et al.,* 2021; Jia, 2024) in the combination of influence of social-cultural factors and participation in the community in technology adoption suggests that approaches require a recognition and a working with the existing social structure rather than working through the mind of trying to work around it. The combination of the findings indicates that the development of sustainable manufacturing practice in Nigeria should be system-based and need to take a technical, institutional, financial, and social dimension all at once. The institutional changes, capacity building efforts and approaches of participation and ownership of intervention by the people need to be supported by the evidences of the prospects of high energy efficiency and technologically viable generation of energy.

CONCLUSION

This systematic review on the 50 most relevant studies manifests sustainable manufacturing systems in Nigeria to comprise an immense opportunity and immense challenge of implementation. Technical feasibility is evidenced by the documented potential of achieving energy efficiency increases by 20-25 percent due to passive design and integration of renewables, and technological transfer routes have and continue to be evident after transfer of technology through community based models where successful adaptation has occurred at the local level. Nonetheless, lingering impediments such as financial, infrastructural, institutional, and policy incoherences persist as a factor to constrain wide use and scaling of sustainable manufacturing practices. The comparative analysis with the rest of other developing economies brings out similar problems they face and also unveils unique limitations that Nigeria faces especially in policy coherence and infrastructure development. There is an imbalance of performance in different sectors of the industry with the automobiles manufacturing being on the forefront of the sustainable activities as compared to on the wider usage amongst businesses. The observance of relative energy decentralization, carbon pricing systems as well as communal modes of innovation channels presages the future that we desire to follow and here, more integrated methods are important whereby developing technologies together with institutional change and societal involvement complements one another.

As the results confirm, there is need to have holistic and region-specific approaches that bridge the gap between the technical courses of action and the socio-political realities. Effective development of sustainable manufacturing in Nigeria will depend on concerted efforts that help eliminate several bottlenecks at the same time, such as a policy shift to create greater regularity and economic incentives, infrastructure upgrades to facilitate renewable energy absorption, capacity building to boost local innovation skills, and community-engaged initiatives that clarify ownership within the community and justify their cultural compatibility with technological interventions. The study can be useful to both scholars and policymakers because of the current contribution of systematic evidence-based knowledge about the intricate dynamics of sustainable manufacturing systems in the context of developing economies, that can be used in future studies and to shape the strategic planning of stakeholders in the study of sustainable industrial development in Nigeria.

CONFLICT OF INTEREST

There is no conflict of interest for this research work.

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