Sustainable Ready-Mixed Concrete (RMC) Production: A case study of Five RMC Plants in Nigeria

Abstract

This study aims to examine whether ready-mixed concrete (RMC) production in Nigeria is sustainable. The study proposed that RMC production will be sustainable, assuming the RMC plant, RMC products, plant management, RMC supply, RMC quality, and demand for RMC are sustainable. Based on a constructivist worldview, the proposition of RMC production's sustainability was assessed by conducting a contextual analysis of five RMC plants in Lagos State, Nigeria. It was observed that the RMC plants required sustainability in power supply, plant output, and plant capacity. The plants have a sustainable supply of raw materials. The management methods and product control strategies were found to be unsustainable. Fair supply time, supply methods, and quality control systems were established in the findings. Challenges, such as administrative issues, economic problems, poor technology, and the absence of an innovative business model, influenced the sustainable demand for RMC products. The study concludes that alternative power supplies and methods like just-in-time (JIT) purchasing systems and learning frameworks ought to be considered for RMC plants. Likewise, improving the ease of doing business would significantly help the sustainability of RMC production. The study presumes that RMC production is, as of now, not sustainable in Nigeria. Still, the sustainability of RMC production could be ensured through measures such as the reuse of waste, the adoption of innovative RMC production and delivery, and technological development.

Keywords: RMC, ready-mixed-concrete, sustainability, sustainable concrete production, re-use-waste, Nigeria

1. Introduction

[1] described RMC as a tweaked and customised product; RMC is produced for contractors at a plant where the unrefined components of concrete are mixed and blended by computerised automatic batching and mixing control systems and conveyed to construction sites by transit mixers or concrete mixer trucks. RMC is a type of concrete ideal for large and small projects where quality should be controlled to suit a series of applicable regulations or standards or a given construction project's established concrete design strength. RMC has been extensively utilised for its low price (in certain regions across the globe), workability in use and adaptability to specified circumstances and constraints of the construction project, compelling production scheduling, and efficient truck dispatching.

In addition, the ease of large construction projects, quicker construction work, decrease of material storage space, waste reduction, project cost savings, and expanding utilisation of uniform and higher grades of concrete are other favourable factors for utilising RMC. The most significant advantage of RMC is the dependable quality of concrete that is achieved through a computerised, contemporary, and programmed mix of the precise quantity of water, cement, sand, coarse aggregate, and other admixtures (where necessary) [2]. Compared to conventional hand mixing, such enhanced accuracy of concrete mix proportions provides relevant quality and reliability in the project and the structural design of load-bearing elements.

Most of the published literature on RMC has been dedicated to mathematical modelling and heuristic methodologies for lessening mixer breakdowns, improving system operating costs, and optimising RMC distribution [3,4,5,6,7]. Various investigations have analysed a mixed-integer linear programming (MILP) formulation for solving RMC distribution [8], a model for contrasting the inventory costs of purchasing under an economic order quantity (EOQ) with a price discount system and a Just-In-Time (JIT) order purchasing system [9], a neural network methodology for RMC batch modelling problems [10], and metaheuristics techniques for the vehicle routing problem time windows [11].

The focus of RMC studies has been on the profitability of RMC plants and activities. So far, however, there needs to be more conversation about the sustainability of RMC's business and production process. Exploring the sustainability of the RMC production process is fundamental because RMC production consumes resources (energy, raw materials, water, and land) vital in accomplishing sustainable development and diminishing greenhouse gas (GHG) emissions. RMC is concrete, and concrete is one of the most applied and versatile construction materials in contemporary construction practice globally. Thus, it will be profoundly fundamental to guarantee the sustainability of concrete to achieve sustainability in construction and the built environment [12].

Since the RMC industry is poised to grow further sooner rather than later, the GHG emissions from RMC production will undoubtedly increase. Considering this, there is a critical need to explore the sustainability of RMC production. This investigation should cover the accessibility of quality RMC equipment indigenously produced or assembled to prompt weighty savings in the cost of construction, the availability of trained and skilled staff to operate RMC plants, the computerisation of RMC operation, the utilisation of appropriate amounts of ingredients as per the contractors' needs, the use of bulk quantities of cement stored in silos instead of bag cement, the use of alternative materials, and the quality and workmanship of RMC produced. This study aimed to examine whether RMC production in Nigeria is sustainable.

Studying the sustainability of RMC production in Nigeria becomes fundamental because of its significance in the Nigerian construction industry. RMC is better outfitted to adapt to changes in Nigerian atmospheric conditions. It is valuable in decreasing the risk of quality issues related to concrete performance in Nigeria, and it helps control the all-out cost of material stockpiling and security in the Nigerian climate [13]. RMC eliminates project delays and prompts quicker execution of large infrastructure projects [14]. The populace's interest additionally exacerbates the requirement for RMC in Nigeria, as the RMC market has been projected to grow past its current size [15]. [16] likewise detailed that the reception of RMC in Nigeria is on the rise as quantity surveyors suggest its utilisation because of the ascent in cement prices. [16] further observed that the strategies and intricacies related to the interest of RMC are driving some RMC plant administrators to cast off the undertaking. This adversely influences the state and size of the RMC market in Nigeria. A comparative situation was reported by [17] in South Africa. This development has placed a strain on RMC production in Nigeria and has required the need to research their sustainability.

2. Literature review

RMC investigations have been significantly concerned with effective production scheduling and truck dispatching. The goal has been to accomplish a compelling and proficient investigation of contractors' demand for RMC and avoid delays in transformation. [18] distinguished the best route in the Mumbai region to optimise the RMC travel time by simulating various routes from the RMC plant to the construction site by applying Geographic Information Systems (GIS) using toposheets, satellite images, and shapefiles. [19] presented a successive genetic algorithm technique that can solve RMC problems in two separate stages with practically no requirement for post-processing. The study by [20] introduced an approach to improve the operation of RMC production and decrease the cost of the whole delivery process. The study proposes a mathematical model of the vehicles dispatching RMC (vehicle in this regard refers to the mixer vehicle used for only delivering concrete and the pump utilised for concrete unloading and casting) with hard time windows.

[21] foster a coordinated model that combines RMC production scheduling and truck dispatching within the same framework. The model is a mixed-integer network flow problem with side constraints. In a subsequent report, [22] utilised network flow techniques to construct a systematic model that helps RMC carriers successfully plan production and truck dispatching schedules under stochastic travel times. In that study, a model is formulated as a mixed-integer network flow problem with side constraints. Problem decomposition and relaxation techniques, coupled with the CPLEX mathematical programming solver, are employed to develop an algorithm that can efficiently solve the problems. A simulation-based evaluation strategy is also ~~additionally~~ proposed to evaluate the model, coupled with a deterministic model.

In the study by [23], a set-up of straightforward moves is utilised to settle real-world instances of the RMC delivery problem. These fundamental moves are used under a selection hyper-heuristic that utilises the new adaptive iteration limited list-based threshold accepting a fixed limit and four others for comparison. The study by [24] proposed a systematic model of delivering RMC that optimises the schedule for dispatching RMC trucks. The study developed a model based on bee colony optimisation (BCO) to observe the best dispatching schedule that minimises the total waiting time of RMC trucks at construction sites.

[25] proposed a novel meta-heuristic approach based on a hybrid genetic algorithm combined with constructive heuristics to determine the intricacy and time limitations of RMC supply earliness and lateness. [26] expanded on a classical economic order quantity (EOQ) with a price discount model to derive the EOQ-JIT cost indifference point. In 2006, Min and Pheng improved on the limitations of the existing EOQ-JIT cost indifference point models and developed the JIT purchasing threshold value (JPTV) models for RMC supply. The study by [21] developed a network flow model for an RMC carrier according to Taiwan's operation situation that integrates RMC production scheduling and truck dispatching in the same framework to decide on an optimal RMC supply schedule that also incorporates overtime considerations. To build the model, the

authors employed a time-space network technique to formulate the production of RMC and the truck fleet flows in the dimensions of time and space.

The model is formulated as a mixed-integer network flow problem with side constraints. [27] developed the dispatching operations of RMC trucks as a job shop problem with recirculation, which incorporates time windows and demand postponement, as well as the external cost of transport, in a multi-objective programming model. The study classified factors affecting truck dispatching of RMC plants into intrinsic and imposed constraints, where inherent imperatives allude to limits that should be fulfilled during the concrete distribution process; forced limitations should be fulfilled to the most significant degree conceivable during dispatching.

[28] proposed a model addressing the generic RMC operation process and customising its structure and parameters for various functional circumstances in a study seeking to develop a dynamic simulation model using system dynamics. The model analysed the RMC supply process and focused on the tradeoff between the truck mixer dispatching interval and queuing time on-site. The study by [29] introduced a methodology for improving production and delivery operations in RMC plants. In the study, a network flow technique is applied to figure out the incorporated scheduling problem of RMC production and delivery with trucks and pumps, where the demands of construction sites are within specific time windows. The genetic algorithm adopted in the model consists of a chromosome of three sequences: construction sites, delivery orders, and vehicle IDs. [30] investigated the role of demand shocks in the RMC industry. Utilising Census information on more than 15,000 plants, the study estimated a model of investment and entry in oligopolistic markets. These appraisals were utilised to reproduce the impact of taking out transient local demand changes.

The above examinations are fixated on supplying RMC in both a reasonable and practical way. These examinations have uncovered that RMC supply issues comprise depot-allocation and truck-allocation problems, that the depot-allocation problem is more muddled than truck allocation, and that the combination of these subproblems compromises the productivity of the solution. The research discoveries indicate that models could help accomplish a prudent RMC supply by keeping up with the number of queuing truck mixers at the desired level while fulfilling the contractor's need. Some of the proposed models have recognised the best and shortest possible route considering various RMC delay-causing parameters. It is accepted that the utilisation of these models will help RMC suppliers in selecting a route for delivering RMC, minimising the number of trucks, generating proficient and adaptable solutions to dispatch RMC trucks through a more excellent solution and faster computational time, deciding on a practical and dependable everyday appropriation scheme, and accomplishing better customer service.

To accomplish better customer service, the studies by [31] and [32] scrutinised the quality of RMC. [31] fundamentally dissected the quality and formation of cracks in RMC structures. The study elucidated the factors critical to improving the quality of concrete produced in an RMC plant and the factors pertinent to improving workmanship while casting the concrete, which will repress the formation of cracks. [32] examined the utilisation of tailings taken from a chrome ore concentration plant in Eskisehir, Turkey, as fine aggregate in RMC production and improvement.

In the study, the tailings were supplanted by the fine aggregate by weight at 0, 10, 20, and 30% proportions by weight in the RMC mixtures.

Ongoing investigations have considered the management of emissions from RMC plants. [33], for instance, developed a methodology for capturing emissions from RMC equipment and material during on-site delivery operations. The study provided more profound insights into the on-site emissions arising from RMC delivery operations and a bespoke methodology that could be used as an organisational learning tool for RMC companies. [34] focused on carbon dioxide utilisation to improve the sustainability of RMC. The study showed that integrating a CO2 utilisation step into conventional concrete production can lessen the carbon footprint of the concrete by 4.6%.

[35] described the evolution of green certification for RMC in India. The study by [1] focused on the source, classification, and management of ~~the~~ processing wastes from RMC plants and their potential re-utilisation. The study classified the RMC plant wastes as reclaimed aggregates, concrete slurry waste, wastewater, and reclaimed water. The study claimed that these wastes could be reused to produce different low-carbon footprint products to improve the sustainable development of the RMC plants. [36] examined the properties of wastewater acquired from an RMC plant and its potential utilisation as mixing water for concrete production.

All the tests conducted by the study showed that wastewater is suitable for concrete mixing water and can be used without any treatment or dilution, contributing to water savings. After all, wastewater of combined dissolved and suspended organic and inorganic solids (at 0.1% content) with water (at 99.9% content). This set of studies has provided ample opportunities to improve the "green" performance of the RMC plants. The methods proposed by this study will enhance the green performance of the products in the RMC industry. They will likewise help accomplish a definitive target of decreasing the GHG emissions from the industry.

3. Method

The methodology of this study depends on a constructivist worldview. Constructivism embraces reality as a construct of the human mind; subsequently, reality is perceived as subjective [37]. In simple terms, according to constructivism, all knowledge is constructed from human experience. Constructivism empowers the researcher to focus on a single concept or phenomenon. The focus of this study is the sustainability of RMC production. The study is planned as a multiple instrumental case study where the case is an RMC plant and five RMC plants are selected in Lagos State, Nigeria, for the study (Figure 1 presents the profiles of the five RMC plants chosen for this study). The choice of Lagos State was informed by its metropolitan status. The demand for higher speed of construction and a large volume of concrete, particularly for residential apartments, commercial complexes, bridges, highways, roads, and aeronautics in Lagos State, demanded the implementation of mechanised and semi-mechanised construction techniques such as RMC [38].

Locating the RMC plant in Lagos State is a good business decision due to the available demand and other opportunities. Lagos State is the Nigerian focal point of greatness, a construction ~~centre~~ financial centre [38]. Presently, Lagos State is encountering workaround infrastructure development and gigantic developmental works like the construction of breakwaters, roads, factories, bridges, and hospitals [38]. The concrete demand for these developmental projects is enormous and necessitates exploring the sustainability of RMC production in the state.

The case study of RMC plants in Lagos State enables an in-depth investigation of the RMC plants. The case study approach in research accommodates and encompasses both in-depth and multi-faceted explorations of real-life settings and applications with varied levels of complexity [39]. The conceptual and vivid focus that case study research provides for in-depth knowledge acquisition justifies its application in this study.

However, the objective of this research approach is that the learning gained from concentrating on one case can be generalised to many others, enabling the researcher to explore differences within and between the plants [40]. Through this approach, the similarities and contrasts between the plants would effectively be perceived [40]. Contrasting results for expected reasons or comparative outcomes in the plants would effectively be predicted through the research approach. The approach additionally empowers the discoveries to be explained as significant or not [40]. In addition, the approach invigorates and gives dependability to the evidence created in this study and permits the study's conclusions to be extended to other RMC plants.

[41] characterised a case study as a research procedure that permits immediate or genuine perception of a peculiarity. A case study was viewed as helpful and essential in this exploration due to the need to assess practical examples of RMC production, determine nitty-gritty clarifications of RMC production sustainability, give a base for approving the RMC production sustainability framework, and produce significant discoveries that would explain the comprehension of the RMC operation and sustainability in Nigeria. The case study was designed as a holistic case study with various units of analysis and led by the contextual analysis processes framed by [41]. The cycles involve:

- c~~C~~onducting an extensive literature review that gives a pre-comprehension of RMC operation and production. This empowered the identification of conceivable sustainability issues that pertain to RMC production;~~.~~
- fostering a conceptual framework of RMC production sustainability to characterise the examination technique that would direct the case investigation;
- choosing the cases. The cases were selected in light of their portrayal of the significant RMC plants in Nigeria, proprietorship blend (indigenous and multinational), and location spread; and
- data collection and analysis.

Following the suggestions by [41], the reliability and validity of the case study analysis were laid out by involving multiple sources of information for every one of the RMC plants. As indicated by [41], data collection from several research participants will lay out the reliability and validity of a case study. Thus, participant and direct observations merged with interviews were utilised to accumulate information about the RMC plants.

To accomplish the target of this study, a conceptual framework for sustainable RMC production was proposed in Figure 2. The conceptual framework recognises what RMC production entails and what production areas require sustainability. The framework likewise serves as an anchor for the study and a guide for data interpretation. The framework gives philosophical, methodological, and insightful support for the study [42]. Aside from providing the structure to characterise the concept of RMC production sustainability, the framework additionally serves as an aid for the research. As displayed in the framework, RMC production will be sustainable if the RMC plant, RMC products, plant management, RMC supply, RMC quality, and demand for RMC are sustainable.

The criteria for evaluating the sustainability of these six components of sustainable RMC production were recognised in the framework. The measures should interrelate in every one of the RMC plants to make the correct conclusion from the data analysis, keep away from traps that go with statistical analysis, inspect if the concepts co-vary as anticipated, and guide the study. As verified by [41], a theoretical framework is expected to direct contextual analyses. The collected data were analysed using cross-tabulation and frequency distribution. The results of the frequency distribution were deciphered as follows: extremely insignificant (0%–20%), insignificant (21%–40%), average (41%–60%), significant (61%–80%), and exceptionally substantial (81%–100%).

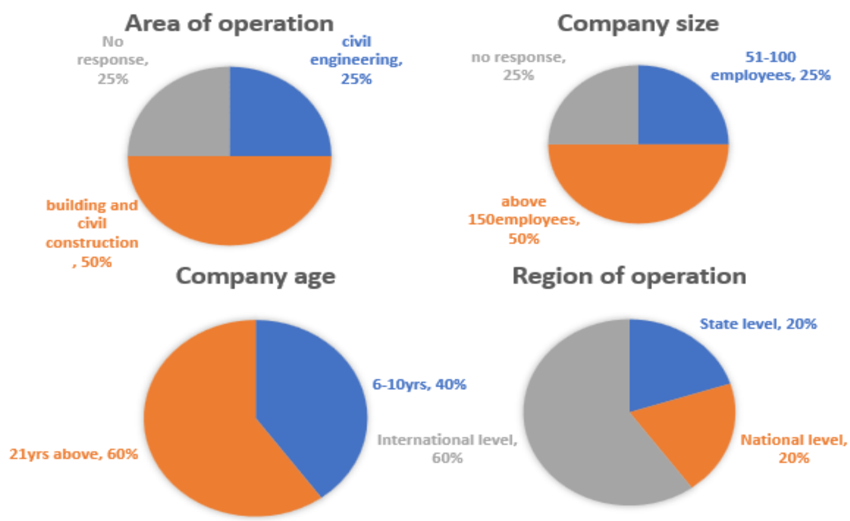

Figure 1: Profile of case studies

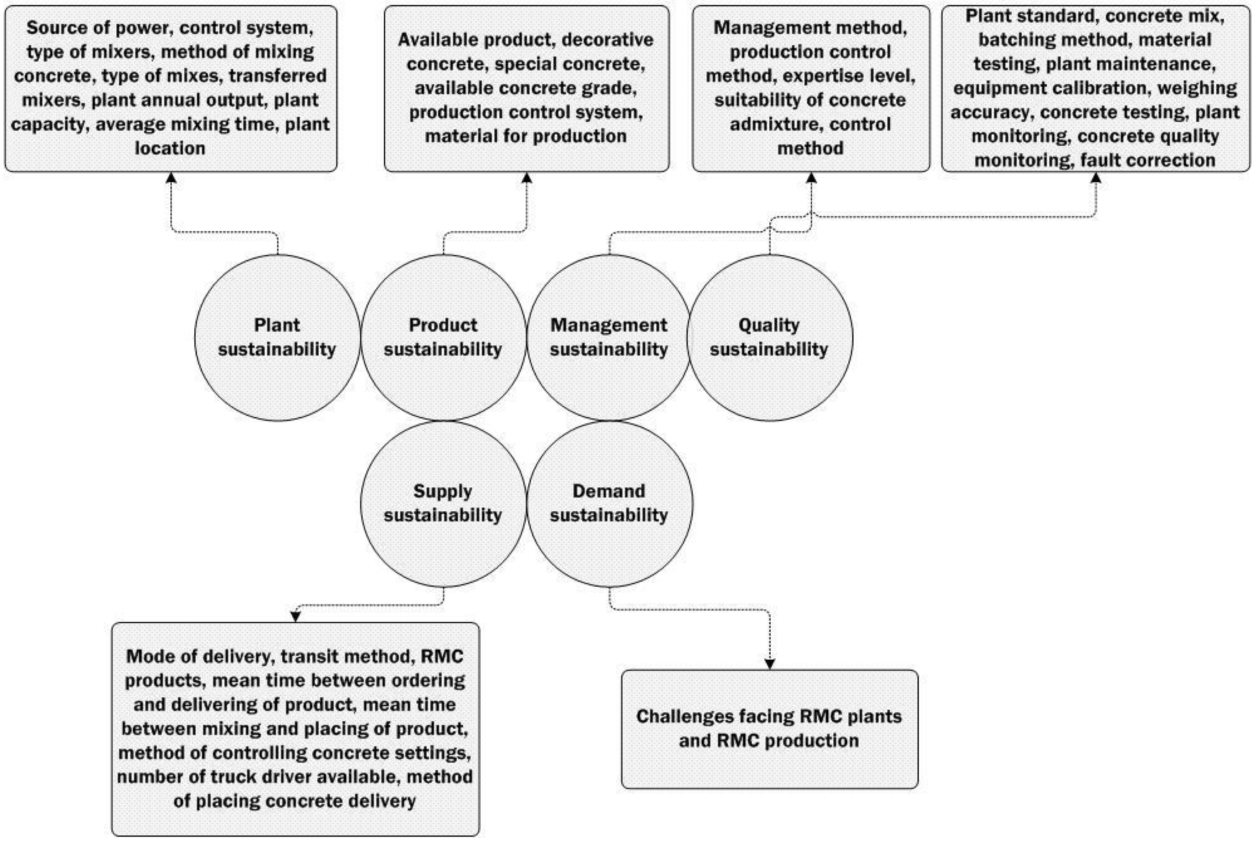

Figure 2: Conceptual framework of sustainable RMC production

4. Results

4.1 A case-by-case analysis of the RMC plants

- Case 1: This RMC plant is owned by a Nigerian financial backer. Plant capacity was not made accessible, yet the respondents recognised that the RMC plant is enlisted and wholly certified. The plant has all standard grades of concrete and works according to ISO 9001:2015. The plant is involved in assembling, selling, and delivering various RMC items.
- Case 2: The plant has a Nigerian investor. The information from the case study participants revealed that the plant is enlisted and certified, has a moderate capacity, and produces all standard grades of concrete. ISO 9001:2015 is the norm used in the plant, and the functional extent of the plant is restricted to deals and conveyance.
- Case 3: A multinational-owned RMC plant in Lagos State with a 10.5-ton limit fully enrolled and involved stringently in the sales and delivery of all standard grades of RMC. The plant abides by BS-EN 12620 for aggregate standards, EN 934-2 for admixture standards, and EN 206-1:2013 for concrete standards.
- Case 4: This plant is a Nigerian-enlisted and affirmed global firm in Lagos State. Its plant limit is roughly 300 m3 per hour. The plant has decisively found its

branches all over Lagos State to convey RMC on schedule, as determined, and within the provisions of ISO 9001:2015. The firm is into manufacturing mobile batching plants and the sales and delivery of RMC products.

- Case 5: An indigenous RMC plant with its headquarters in Lagos State The plant has the capacity to supply as much as 5 million tons of RMC items consistently. Likewise, the plant offers nearby concrete batching and production services for contractors and project managers that want to utilise customised specifications and specific materials. The plant conforms to the ISO 9001:2015 standard.

4.2 Plant sustainability

This study perceives plant sustainability as an indicator of sustainable RMC production in Nigeria; hence, the sustainability of RMC plants was first considered. Ten criteria were utilised to evaluate the plant's sustainability. The results of the evaluation, as shown in Figure 3, revealed that the plants have sustainability in the areas of control system (80% fully automated), types of mixer (70% tilting drum mixer), method of mixing concrete (80% central mixed concrete), types of the mix (100% designed mixes), transferred mixers (80% conveyor belt), and plant location (100% availability of raw materials, 100% nearness to demand, 100% supply of labour, 100% power supply, 100% supply of capital, 100% government subsidies, and 100% waste disposal). This result suggests that the RMC plants needed sustainability in power source, transferred mixers, annual plant output, plant capacity, and average mixing time.

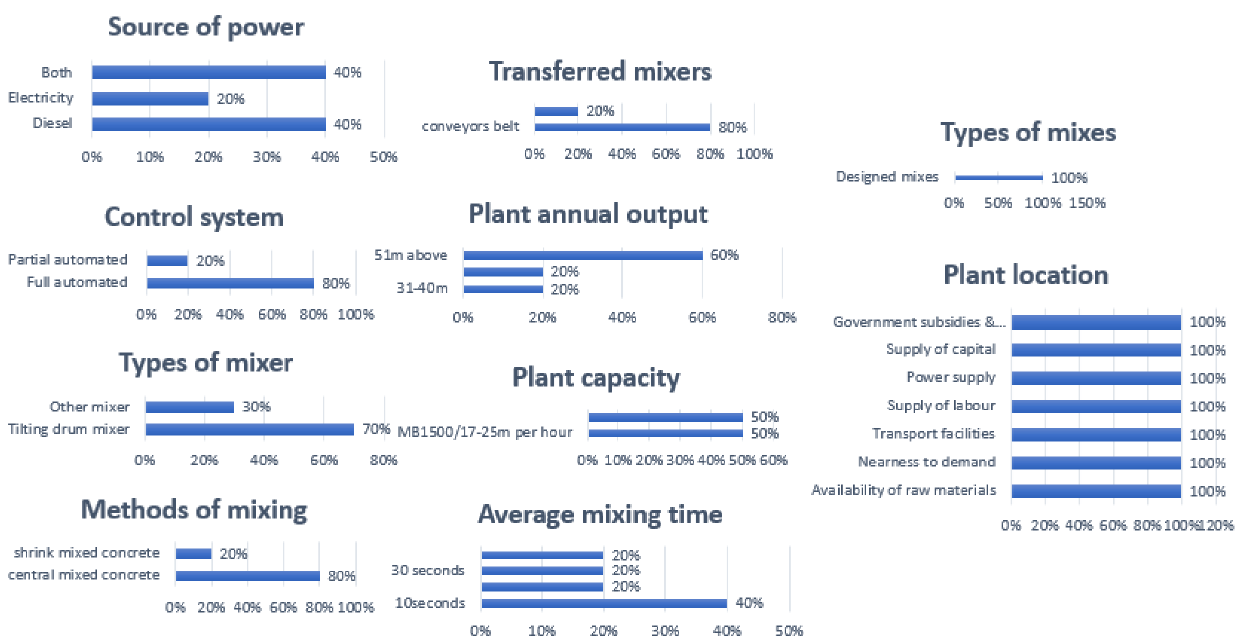

Figure 3: plant sustainability in RMC production

4.3 Product sustainability

The results of the analysis of RMC product sustainability are introduced in Figure 4. It is seen from the results that the RMC plants have various kinds of RMC products. Various sorts of RMC products, for example, self-compacting concrete (100%), high-strength concrete (100%), concrete blocks (100%), mortar (100%), and precast concrete pipes (100%), are available at the plant. Additionally, every one of the plants has RMC with coloured cement (100%), colour aggregate (100%), polished aggregate (100%), and exposed aggregate (100%). As uncovered in Figure 4, the plants have provisions for special RMCs such as self-consolidating concrete (100%), high early strength concrete (100%), low shrinkage concrete (100%), and fibre-reinforced concrete (100%). Raw materials for producing these RMC products were additionally affirmed to be accessible.

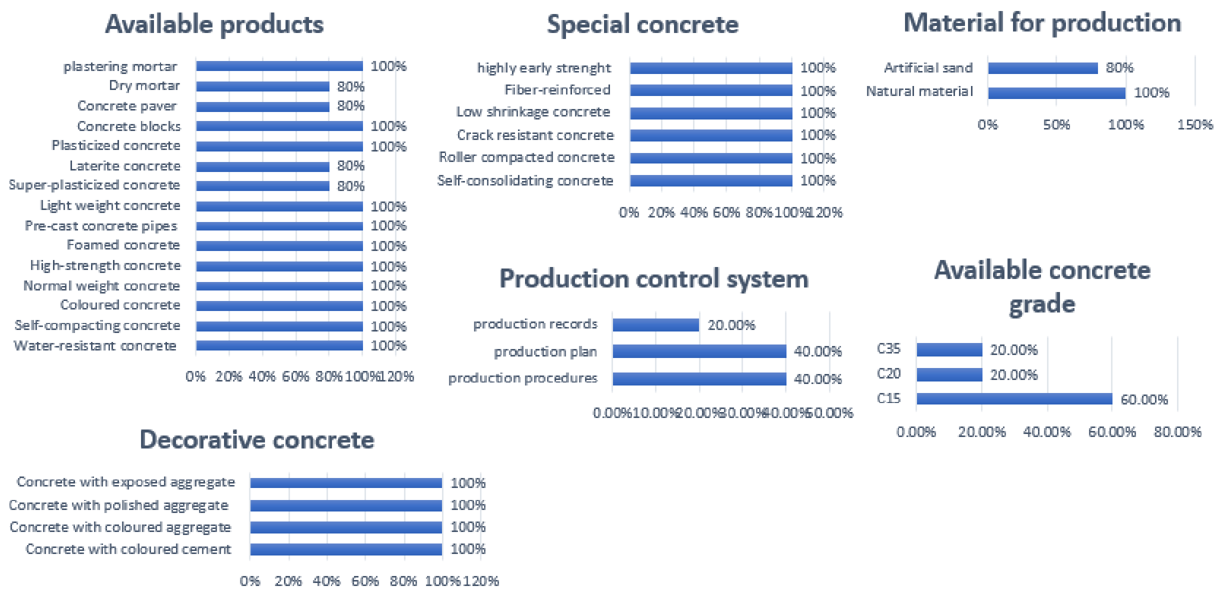

Figure 4: Product sustainability in RMC production

4.4 Management sustainability

Figure 5 shows the details of the management sustainability of the RMC plants. The figure shows that the management guaranteed that the plant workers are skilled and well-qualified (100%) and that sustainable concrete admixture is utilised for the RMC products (100%). This aspect of management practices is excellent, as it will shield the product's quality and the workforce handling the production process. Even so, the results of the management methods and product control management revealed that the strategy could be more sustainable.

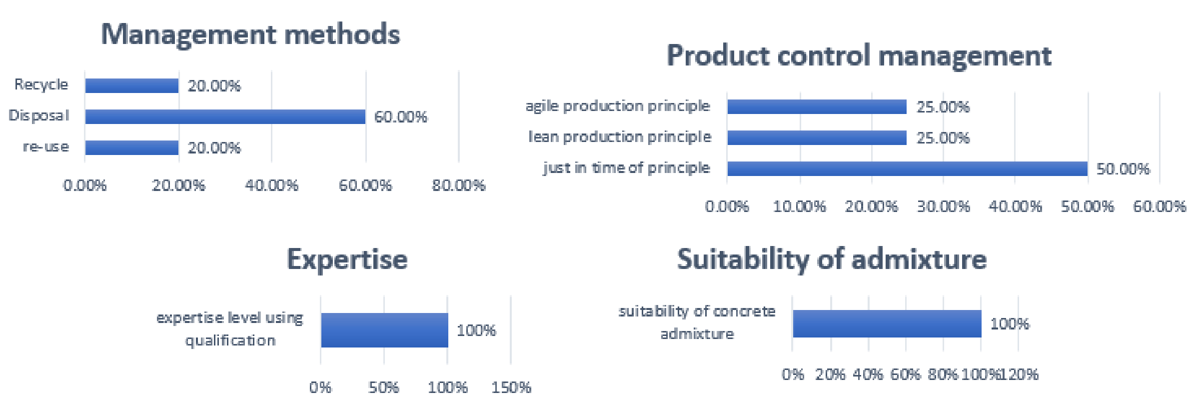

Figure 5: Management sustainability in RMC production

4.5 Quality sustainability

The results of the analysis of the quality and sustainability of the RMC plants are introduced in Figure 6. As displayed in the table, every one of the plants adheres to international standards for RMC (ISO9001:1994 (80%), ISO9001:2008 (100%), ISO14001:2004 (100%), BS EN ISO9001:2008 (100%). Material testing such as water consistency (100%), chemical analysis (100%), inspection of mixers (100%), batching systems (100%), admixture dispensers (100%), weighing equipment (100%), and conveyors (100%) are regular in the RMC plants. Calibration of testing equipment (100%) and water meters (100%) were affirmed to be carried out in the plants. After production, the RMC is tested for uniformity (100%), cohesion (100%), consistency (100%), compressive strength (100%), air content (100%), cement content (100%), and workability (100%). The plants are monitored by making observations (100%), reporting changes in materials (100%), and reporting changes in batch quantities (80%). The RMC is monitored by sampling concrete quality (80%) and re-testing concrete quality (80%). Faults detected are diagnosed (100%) and corrected (80%). This result showed that the RMC plants have a system to sustain RMC quality.

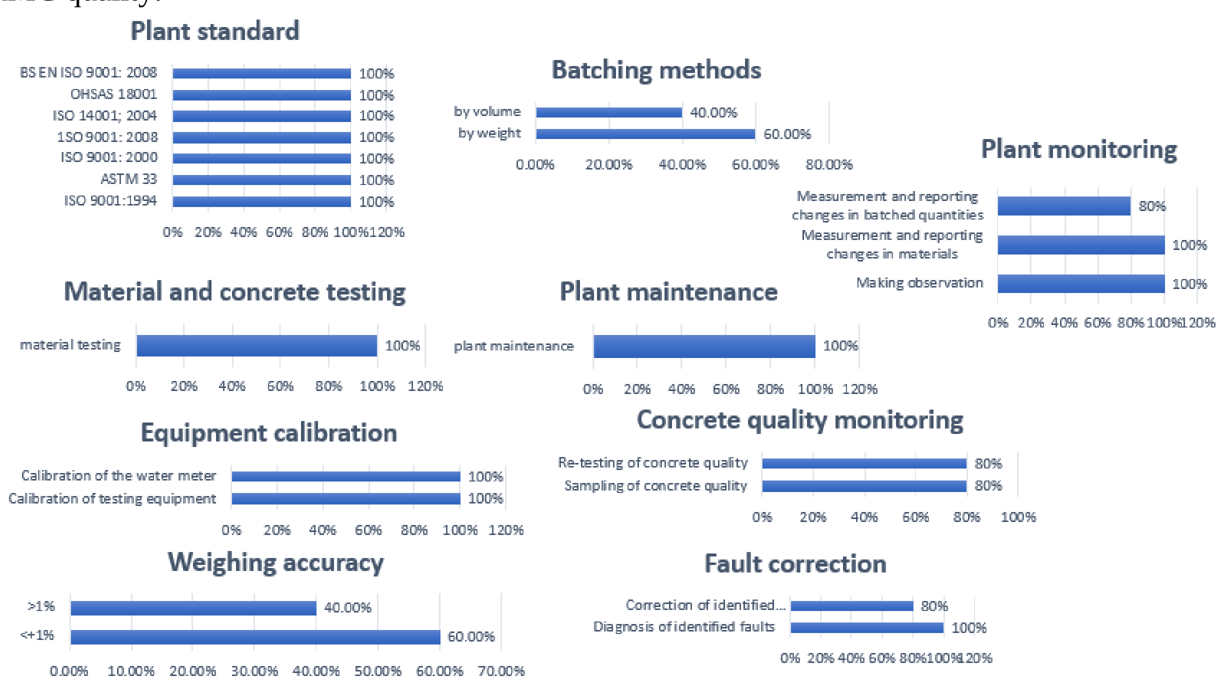

Figure 6: quality sustainability in RMC production

4.6 Supply sustainability

Figure 7 presents the details of the supply sustainability of the RMC plants. It tends to be seen from the table that the mean time between ordering and delivery of products is 24 hours (80%), the mean time between mixing and placing of concrete is 100 minutes (75%), and the methods of placing concrete delivery include a pump (100%), bucket (80%), chute (100%), deposit from a truck (100%), buggy (100%), and belt conveyor (100%). These results suggest that the RMC plants have decent supply times and supply methods.

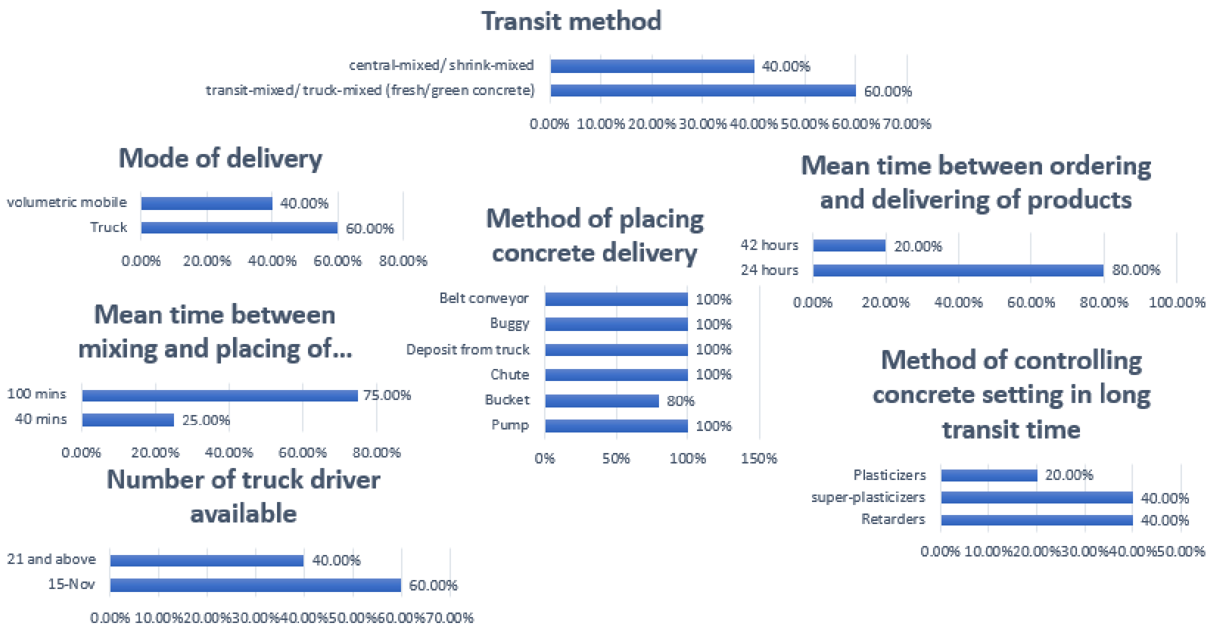

Figure 7: supply sustainability in RMC production

4.7 Demand sustainability

To investigate RMC demand sustainability in the RMC plants, questions were asked on the challenges affecting RMC demand. The rationale was that if there are difficulties influencing RMC demand, then the nature of the challenges would inform the degree of RMC demand in the plants that can be kept up with or refined. The results of the analysis of RMC demand sustainability are introduced in Figure 8. The results indicated that there is a low demand for RMC products (100%), regulatory problems (80%), economic problems (100%), poor technology (100%), a lack of an innovative business model (100%), poor cultural changes (80%), and productivity loss (100%). Different challenges affecting RMC demand are recorded in Figure 8.

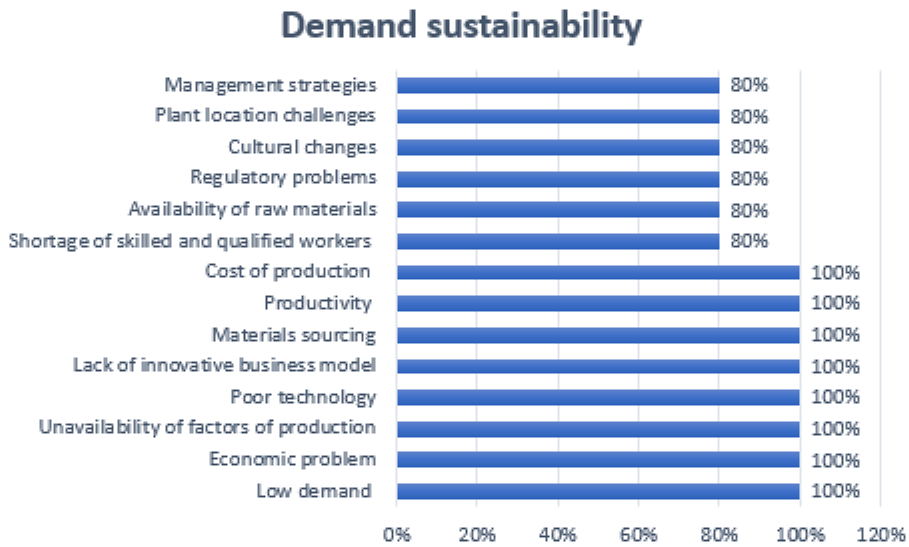

Figure 8: demand sustainability in RMC production

5. Discussion of findings

It emerged from the findings that the RMC plants have access to raw materials and labour. Raw materials assume a significant role in the production process of RMC to a great extent, as the number of raw materials determines the business's success [43]. RMC plants with raw materials do not require the importation of raw materials and will quickly increase profits. The availability of raw materials is the most pivotal part of production [43]. Labour availability falls into a similar category as the accessibility of raw materials. Labour is the most dynamic factor in production [44]. It is transitory in nature and should be persistently accessible. In any case, the RMC plants have power supply vulnerabilities. This has an enormous financial effect on the plants.

It implies that the economic growth of the plants is not guaranteed. This is because as the sustainability of the power supply declines, economic growth will likewise decline [45]. An impractical power supply will prevent the RMC plants from meeting business pressures and demands. A power supply is the primary input to production [45]. A plant without stable electricity indeed amounts to non-mechanised production. This clarifies why some of the RMC plants are only partially automated. Production is at risk of disruption if the power supply is not reliable. Likewise, an unreliable power supply will impact the solidity and efficiency of the tools and equipment for RMC production. Designing the plant for the maximum expected demand will be unthinkable. It likewise implies that the RMC plants may need to be more competitive in their performance.

The findings revealed that the RMC product could be more sustainable in terms of the production control system. Most plants deliver a limited range of concrete grades and need an established production plan. Keeping production records was rare among the RMC plants. The availability of a wide range of concrete grades at the plants should be possible because of the absence of interest in a few concrete grades. It may be due to the absence of accentuation on the concrete grades by the users of RMC products. Concrete grades characterise the base strength the concrete should have.

Specifying the concrete grades is one way of guaranteeing the concrete structures' efficiency. It may be the case that RMC plants are not making information accessible on the available concrete grades since they need to satisfy their needs no matter the concrete grade specification. In this situation, higher concrete grades might be supplied for lower concrete as requested by RMC users and because it is an available RMC product. The opposite may likewise be the case, assuming this is happening at the RMC plants; the productivity and dependability of RMC plants are in question.

The discoveries on the non-record keeping and lack of production plan illuminate that the RMC plant operators need to check the advancement of their business. Production records can show whether the RMC business is improving, which RMC products are selling, and what changes the plant needs to make. Keeping records will help with the concrete grades that sell the most. This will help them manage their accounts, interests, working costs, and taxes effectively. The RMC plant operators depend on auditing the business records. Be that as it may, the auditing system's exactness relies on the production records' precision. A sales and supply record cannot uncover the subtleties of production.

Most RMC plants opt for disposal rather than reuse and recycling. Reuse is a system that conserves resources, decreases the waste stream, and causes less pollution. It is often a method to make a new product. It provides an astounding, ecologically preferred, and sustainable alternative to disposal. The fact that the RMC plants need to take on this technique could be because of the absence of innovation and a system for re-utilising. RMC plant operators are not concerned about the environmental effect of dumping RMC products as waste and that the business is so lucrative that reusing is not considered an option.

Cement is expensive and essential in the production of RMC. With recycling, non-renewable resources like cement can be conserved. This will diminish the demand for cement as a raw material, increase the profit level of the business [1,35], and lessen the carbon footprint of RMC [33]. Cement is the material that consumes the most significant amounts of energy in both the transportation and production stages of RMC [46]. As noted by [33] and [46], the carbon footprint of the RMC plant is high because it generates greenhouse gases through on-site emissions and on-site delivery operations [33]. [46] revealed that to produce 1 m^3 of RMC, RMC plants require 568.69 MJ of energy, accompanied by 42.83 kg of CO_2. Indirect transport generates the most significant environmental impact, especially the transportation of raw materials, which represents approximately 80% of the embodied energy and 79% of CO_2 emissions [46].

It arose from the findings that just-in-time (JIT) principles, the learn production principle, and the agile production principle are uncommon among RMC plant operators. This could be because RMC plant operators use a demand-pull framework to manage RMC production and delivery. This traditional method has been demonstrated to be ineffective [3,9,47]. JIT is a management strategy for eliminating overproduction. It balances supply with demand and eliminates the accumulation of unsellable products. Different JIT frameworks for RMC production have been proposed by [4,8,26]. The lack of utilisation of these frameworks by the RMC plant operators could be credited to the absence of interest in finding out about beneficial RMC production systems or the absence of mindfulness. The significance of lean management and production in RMC plant management cannot be over emphasised. The principles of lean output improve efficiency, waste reduction, and productivity.

Innovation and quality control that would have been squandered would be used through lean standards. These principles have demonstrated a profoundly effective business management philosophy. Utilising lean principles within a production facility, for example, an RMC plant, is fundamental to sustainable RMC production in a country like Nigeria. While the learning principle creates value by maximising productivity and minimising wasted effort and expenses, the agile principle creates value by maximising cooperation and minimising risk and time-wasting. With production bottlenecks and make data-driven decisions to address them. From this study's findings, the management of RMC plants is not aware of the advantages of these principles and their application in RMC production and delivery.

The findings indicated that the plants' batching methods and weighing accuracy could be more sustainable. Also, only some of the plants batch by weight, and not all weigh their materials accurately. Weight batching has an extraordinary benefit, giving good-quality concrete and a more exact and steady mixture. Because precision is very important in batching, weight batching is always better than volume batching, especially due to the incidence of sand bulking, which increases sand volume due to increased moisture content. With more precision in the weight, one of the advantages of RMC is that if the plants in Nigeria are not stringently batching by weight, it may be the case that they are not focusing on schedule, cost, and batching space on construction sites. The contractors know what to expect from the RMC when submitting their requests and the concrete placement methods. This implies that contractors can prepare for concrete production and placement with assurance and design construction methodologies for concrete structures based on the known RMC supply method.

What should have been laid out concerning RMC supply are the transit method, mode of delivery, number of truck drivers available, and technique for controlling concrete settings during lengthy travel times. The optimisation of RMC supply has been connected to the transit method [48,18], mode of delivery [20], number of trucks [11], and control of concrete setting [25]. This implies that accomplishing the best customer service relies upon balancing supply and demand. Earliness and lateness of RMC supply financially affect both the contractor and the scheduled RMC supply time; sitting tight for RMC supply or having to work with a late RMC supply will influence the cost and quality of the work. Assuming the contractor dismisses an early or late RMC supply on the ground that the quality is compromised, he might be justified, and the RMC supplier will experience financial misfortune.

This result suggests that the sustainability of RMC demand depends on infrastructural development, technological development, the simplicity of carrying on with business, adopting RMC, improved management strategies, and training concrete technologists on RMC production. Infrastructural development requires construction projects that will consume a large volume of concrete. Manual concrete production can only supplement the demand; the bulk of concrete for such projects will be acquired from RMC plants. This would boost RMC demand. The sustainability of RMC demand additionally relies upon native RMC plant technologies. The availability of Nigeria-made RMC plant technologies will lessen the investment cost in RMC production and supply. At this moment, most Nigerians presumably see RMC as a luxury that only multinational firms and large projects generally situated in Lagos State can afford.

Poor cultural changes, regulatory issues, and a shortage of skilled workers impact RMC demand. This suggests that the significance of RMC has yet to be entirely embraced by the government and individuals. It shows training inadequacies where the labour market's concrete technologist, building technologist, and civil engineering technologist are considered unfit for overseeing and operating RMC plants. The government still needs to set up regulations and guidelines to support and control the operations of the RMC plants. This could have affected the degree of mindfulness and adoption of RMC among the contractors and the workers. On the part of the RMC plant operators, aggressive marketing and advertisement are missing, and current RMC production strategies still need to be taken on. This clarifies why the absence of an innovative business model, material sourcing, a high cost of production, and poor management strategies impacts RMC demand.

The sustainability of RMC production could be ensured by adopting international best practices. For example, Ready-mix USA uses proprietary products such as low-shrink concrete, polypropylene fibre concrete, internal waterproofing concrete, pervious concrete, and internally reinforced concrete to make its operations sustainable. Experts have identified the reuse of wastes, innovative RMC production and delivery, varying number of mixer revolutions, mixing time and revolution count of an RMC truck, use of blended cement system containing rice husk ash (RHA) and chemical admixture, use of blended cement system containing fly ash, energy management system, plant technology, plant retrofits, and less carbon-intensive fuels, and Internet of Things applications as measures of reducing embodied emissions in RMC and enhancing sustainable RMC production [49,50,15,51,52,53].

Implications for RMC-based Practice, policy, and Research

The alternative power supply should be considered for RMC plants. Full automation of the plants and satisfying the expected RMC demand need to rely exclusively upon a steady and dependable power supply. The promotion of RMC products should stress the available concrete grades, their usefulness, and the available concrete grade options to look over. Keeping supply, demand, and production records is fundamental for the sustainability of the RMC production business. Auditing accounts extraordinarily depends on production records as well as supply and demand records.

RMC plant operators should support research on innovations and techniques for reusing and recycling RMC products. RMC plant operators must endeavour to batch by weight and maintain accurate materials weighing. The scheduling of RMC production and dispatching of RMC trucks should be done according to the available delivery mode, distance, and available truck. This is essential to safeguard supply and maintain superb customer service. The business of RMC production requires ferocious procedures like JIT and lean frameworks. It will benefit the sustainability of RMC production if the management and workforce are trained or informed about the latest RMC production technologies and knowledge.

The government ought to improve the ease of doing business in RMC production. Favourable legislation should be set up. Construction sites and high-rise buildings should be mandated to utilise RMC. Concrete technologists and construction experts should be trained in the production and utilisation of RMC. This will boost RMC adoption and the availability of qualified workers for RMC production. Indigenous RMC plant technologies should be developed. Investigation into RMC trucks that are compatible with the terrain and climate in Nigeria is an example of RMC plant technologies that could be ventured into.

6. Conclusions

RMC production consumes resources fundamental to accomplishing sustainable development and lessening GHG outflows. Furthermore, the GHG discharges emanating from RMC production will, without a doubt, increase because the RMC industry is ready to develop further in the near future. Consequently, this study investigated the sustainability of RMC's business and production process. The RMC plants were found to have access to raw materials and labour. Nonetheless, the sustainability of these plants is undermined by power supply vulnerabilities, deficient automation, non-competitiveness, the non-keeping of production records, and the non-indicating of the available concrete grades. Similarly, the RMC plants need to be more sustainable in terms of the production control system, outright disposal of waste without measures for reuse, and absence of interest in finding out about beneficial production systems.

It is the conclusion of this study that an unreliable or illogical power supply will prevent the RMC plants from meeting demands and that the ecological impacts of RMC plants will aggravate if efforts are not made to curtail them. The use of the demand-pull system for RMC production and delivery will frustrate the advancement of RMC business in Nigeria. There are numerous principles and systems that the management of RMC plants could exploit. Adopting these systems, along with technological development and improved management strategies, will help the RMC plant operators counter the impacts of the difficulties of RMC demand.

This study has made conceptual, empirical, and methodological contributions to the body of knowledge. Conceptually, this study has added to the idea of sustainable RMC production and operation. This study has revealed that plant, product, management, quality, supply, and demand sustainability make sense of the different parts of sustainable RMC production. The framework can be utilised to direct the process of achieving sustainable RMC production and to assist with acquiring a comprehension of RMC operation and management. Empirically, this study offers an evidence-based observational investigation of RMC production sustainability and has determined the degree to which RMC production is sustainable in Nigeria.

The main methodological contribution of this research has been the contribution and application of the hypothetical system and contextual analysis to research RMC production sustainability. The effective utilisation of this hypothetical structure contributes towards illustrating RMC production sustainability in non-industrial nations like Nigeria. Another methodological contribution of this study lies in the experience gained through the application of multiple embedded case studies. This experience might be valuable for different RMC distribution, production, and management examinations.

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