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Green logistics for fresh produce farming: Barrier analysis and opportunity mapping for retail markets

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ABSTRACT

Achieving sustainability in logistics operations is increasingly pivotal for small-scale farmers and business entrepreneurs, particularly in fresh produce markets where efficient supply chain management is crucial. This paper addresses the pressing need to enhance operational and environmental efficiency across logistics processes, including transportation optimization, waste reduction, effective routing, capacity utilization, fleet management, and environmental impact mitigation. The study examines the profound implications of these factors on food quality, spoilage rates, and overall operational sustainability for small-scale farmers from a technology adoption perspective. By highlighting the procedural challenges faced by producers, transporters, and retailers throughout the logistics cycle, this research underscores the necessity for low-cost, customizable technical solutions. These solutions empower stakeholders to adopt sustainable practices, thereby minimizing en-route food waste and operational losses. Ultimately, the paper reviews key sustainability challenges within the small to medium logistics industry and proposes actionable strategies to foster sustainable development across the daily logistics cycle.

1. Introduction

1.1. Background and motivation

Small-scale farmers are the backbone of Small to Medium Business Enterprises (SMBEs) and enabling SMBEs to achieve sustainability in their daily logistic operations is crucial due to several factors [20,38]. Firstly, given the perishability factor associated with various categories of products, including dairy, meat, fruit, vegetables, flowers, and even blood, maintaining adequate fleet vitals becomes critically important. In connection to that, fleet health check-ups, overall sensors' management including temperature and humidity control, fuel consumption, hazard management, and many other factors need to be monitored in real time as indicated in [19] from a thorough logistics-control perspective. Secondly, transportation factors such as optimal routes management, orders time management, loading, and unloading are all essential to co-exist in harmony [8,34] for achieving an operationally sustainable logistics system with timely and waste-free deliveries [4,44] Thirdly, certain environmental factors, including weather conditions, energy efficiency, and carbon emissions, are also frequently considered to maintain operational greenness by having a reduced carbon footprint [1,25].

The current practices in fresh produce markets from logistics point of view [9], evolution of smart-agricultural practices for energy-efficiency [33], sustainable practices for food-waste management [36], and the government regulations for food safety in the developed world [30] influence researchers and technologists to design smart supply chain solutions with seamless integration to existing fresh produce businesses and operations [29,31]. However, it has always been a big challenge to bridge the gaps across different logistics operations i.e., smooth transportation with zero waste, effective routing and distribution, maximum capacity utilization, tracking and tracing of fleet vitals, produce management, efficient fuel consumption, and environmental impact data [18,35]. There have been a number of initiatives under this domain in different dimensions, including academic research [7,13,23] and industrial solutions as well, [6,10,16], but there exists a significant margin of operational optimizations due to a couple of reasons : (1) there is a trade-off factor associated with all the variables listed above (2) the solutions are not specifically targeted for small-scale farmers or SMBEs, being complex, licensed and expensive to use over time . That is why the research phenomenon discussed as part of this research i.e. "Green logistics for fresh produce farming," has a clear-cut motivation across all the relevant dimensions, including design of traceability systems and

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tracking services (System goal), use of advanced sensor technologies such as Internet of Things (IoT) (technology goal) and design of smarter supply chains (knowledge goal), with a focus on operational sustainability for highly subtle fresh produce sectors (end-user goal).

The scope of this research focuses on waste prevention strategies through the adoption of sustainable practices rather than waste management or conversion strategies. Moreover, this analysis is specifically tailored for SMBEs, presenting a survey-based barrier analysis of these SMBEs across multiple logistical states (namely demographic, operational, and transportation) to highlight the internal and external business challenges faced throughout the entire business cycle from the perspective of key stakeholders in the supply chain. The primary motivation is to identify the root causes and trace the associated factors behind these challenges, which will ultimately aid in reducing "en-route food waste" (perishable food waste during transport), a significant contributor to which SMBEs are, due to their limited resources. After investigating several relevant studies mentioned above and below, it is apparent that there is a lack of preventive, proactive, and predictive measures from a sustainability perspective within a comprehensive built-in logistics solution for SMBEs. Henceforth, it is inevitable to review the prime sustainability challenges currently faced by the small to medium logistics industry [24,39] and consequently, recommend state-of-the-art technological adaptations from the stakeholders' perspective itself, through market analysis and stakeholder engagement.

1.2. Related literature

The relevant literature encompasses several research reports and systematic reviews related to fresh produce logistics and sustainable operations. According to the United Nations Environment Programme (UNEP), a published survey of food waste reveals that globally, a staggering 14 % of food is wasted during the supply chain, specifically in transit, storage, or processing [14]. Similarly, a number of other relevant studies and reports, highlight the food spoilage and wastage issues either presenting a cold-storage perspective or discussing mechanical losses, as in [12,27,40]. Similarly, the sources of food spoilage and wastage have been explored and highlighted across main fresh produce categories including fruit, vegetables, and meat from a cold chain solution's perspective, in a report from the ExpertGroup prepared for the Australian Government Department of Agriculture, Water and the Environment, and Refrigerants [31]. This strongly suggests the need to explore contributing factors behind this waste percentage reported across multiple forums of fresh produce-related research. Several comprehensive, systematic literature reviews highlight the burgeoning need for effective and efficient supply chain management practices. As reported in a study on Indian Agri-fresh food supply chains (AFSCs), approximately one-third of Agri-fresh products such as fruits and vegetables are wasted every year in India and the relevant survey results show the maximum attention from the respondents was received by "challenges incorporating the perishability" [22]. Similarly, the identification of crucial barriers to sustainable logistics of fresh produce and their hierarchical structuring are of utmost importance as highlighted and implemented in [43]. All these studies present food waste statistics using systematic literature reviews or different case studies; however, stakeholder engagement from a logistics perspective, specifically from the viewpoint of Small to Medium Business Enterprises (SMBEs), remains negligible. This gives rise to the need to conduct market-level surveys, focusing on a sustainability perspective with maximum stakeholder engagement from SMBEs, to highlight their real-time needs and technical shortcomings. Identifying the real-time challenges and drivers behind these challenges in a multi-dimensional environment through stakeholder engagement and market analysis automatically aligns a smart supply chain design to capitalize on opportunities to mitigate the effects of food waste [28].

Furthermore, several scientific research publications and survey-based studies in the fresh produce sector, indicate the importance of factors related to the storage and transportation of edible food. In connection to that, the implications of these critical factors on food spoilage, quality control, and operational sustainability from the consumer perspective have been explored and highlighted in these relevant studies [26,42] and others. Similarly, surveys and studies have also been conducted using different approaches including Multi-Criteria Decision-Making (MCDM) for green transportation systems [41], Interpretive Structural Modelling (ISM) for developing a structural model of crucial logistic barriers in fresh food transportation [32] and Bayesian Best Worst Method (BBWM) for risk management in smart agri-logistics [11]. All these studies try to employ the best techniques of statistical analysis from consumer perspectives [37] and also agree that due to the sensitive nature of the produce, a smart and effective logistics network is a viable solution [2] but what is left un-answered is the identification of on-field logistics related challenges faced by the key actors of fresh produce supply chain i.e. farmers with indirect actors and constraints i.e. government agencies and regulatory authorities, administration of food markets and others. These logistics-related challenges encompass both inbound and outbound logistics, as well as the corresponding operational states, which are subject to certain technological limitations. Studies or surveys covering these multiple dimensions of analysis (demographical, operational and financial) with stakeholders' engagement specifically from the perspective of SMBEs were hard to find. A closely connected research by [21], tries to cover these aspects of food safety for conventional agri-products (vegetables) in the markets of the city of Tirana, Albania. Similarly, in close connection to our theme, [3] investigates the contractual pain points of farmers with lead firms, intermediaries, and wholesalers, and how it affects the adoption of Sustainable Agricultural Practices (SAP) in the vegetable sector in Chile (which have received little attention in the scientific literature as claimed by the authors) [15] suggests enhancing farmer linkages to markets in developing countries through transport optimization of Freight movements in Indonesia and Vietnam, which is characterized by high transport and logistics costs.

This research aims to highlight the critical nature of these variables, which is linked to several procedural problems that producers, transporters, and retailers face during the logistics cycle. Providing the availability of these edibles to end users (consumers) via farmer markets, food markets, retail stores, on-farms collection stores, food warehouses, grocery stores etc., has its own set of challenges [17]. During this demand and supply cycle, small businesses and business owners, including farmers, face barriers to implementing their daily operations in a sustainable manner, specifically from a green supply chain perspective. Due to limited resources, small-scale farmers often rely on either third-party logistics or handling the logistics cycle themselves, acting as both growers, providers, and sellers simultaneously. It is therefore necessary to understand their challenges and requirements to implement low-cost technical and customizable solutions for them that could shift their daily operations towards sustainable choices, avoiding losses and leading to less waste [5].

In this paper, we provide a survey-based analysis of fresh produce markets from a logistics perspective, highlighting their needs and shortcomings, operational constraints, and challenges, and then propose a balanced IT solution that could support them in carrying out their daily operations. More specifically, this research aims to provide a systematic analysis of technological advancements, standardizations, challenges, and solutions for fresh produce SMBEs from an operational sustainability perspective, i.e., achieving greenness in their daily logistics operations. By conducting surveys and interviews, the primary objectives of this systematic analysis were successfully achieved. The main contributions are as follows: (1) Exploring the current operating states of small businesses selling fresh produce across different farmer markets in Australia from a sustainable logistics perspective. (2) Understanding and highlighting the factors and originating stakeholders behind the barriers faced by these small-scale businesses (farmers) in achieving operational sustainability, i.e., going green. In relation to these objectives, the answers to the key research questions are as follows: 1. What are the prime

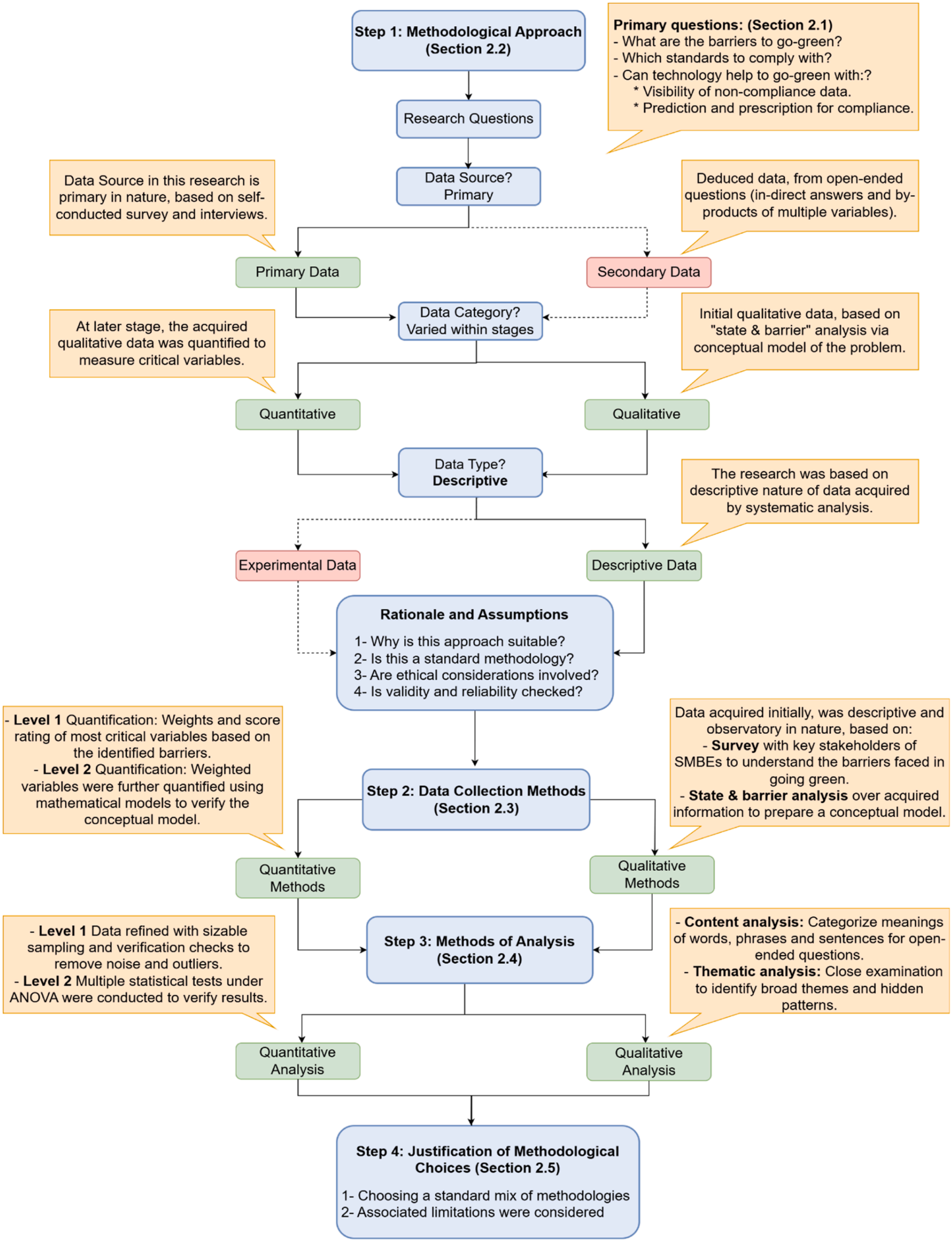

Fig. 1. Detailed methodology flowchart.

sustainability challenges currently faced by small-scale fresh produce businesses from a logistics point of view? 2. What factors make it difficult for small businesses/farmers to move toward green logistics despite having the current assets at hand? 3. Where is waste across the logistics operations? 4. How can small-scale business managers or owners monitor key sustainability parameters across their assets and service them in a timely manner using predictive analytics? 5. Are there any planned or implemented green initiatives already in place, and how can technology help smooth out the current practices and processes?

The paper continues as follows. Section 2 focuses on problem formulation and methodological approach. In the following Section 3, market segmentation and conceptual models are presented. Survey design and recruitment strategy are listed in Section 4. In Section 5, results are discussed. Mathematical formulations for validating those results are tabulated in Section 6. Section 7 proposes an ecosystem-based solution and its implications as part of the future works of this research. Finally, Sections 8 presents the conclusion.

2. Research methodology

2.1. Problem statement

As highlighted in the discussion above, from an operational sustainability perspective in the supply chain cycle, there is a need to explore and highlight the barriers that prevent SMBEs from adopting green practices despite having existing assets. Our survey closely connects sustainability practices, problems, and challenges for fresh produce farming businesses from stakeholders' perspective. It is comprised of a three-dimensional analysis involving (1) Analysis of the current logistic practices and operational states and the exploration of different sustainability practices in action or planned for the future by small-scale farmers. Moreover, what were the specific reasons behind the current and planned initiatives? Furthermore, what are the challenges faced in practicing sustainable farming operations? (2) Analysis of the levels of smart sensors support, transportation services (least to most challenging from a waste generation perspective) and en-route quality management barriers (least to most challenging) (3) Analysis of current operational practices (loading, unloading, labelling, packaging) and degradation expenditures, managing returns and primary reasons of returns, loss due to en-route quality control issues, recycling and waste management means, discounted channels in practice, desired areas of sustainable operations, lack of awareness regarding sustainability among small business owners and government regulations on green initiatives. This three-dimensional analysis helps us to have an in-depth understanding of their problems and then propose low-cost solutions for them, which could technically help them carry out their daily operations, including transportation from farms or warehouses, order management, packing, and waste management in a sustainable manner.

A significant research gap exists in the standardization dimension for assessing sustainability levels among small to medium businesses. Moreover, there is no helpful index on any threshold value or minimum percentage level at which logistics firms should comply with these standards to achieve a greener approach. Having limited resources available to SMBEs, it poses a challenge for them to go green by achieving compliance with go-green rules. Therefore, to target what could be the minimum set of rules that SMBEs can comply with without huge cost and resources, there is a need to conduct local market surveys to analyse their current operating states and conduct a state and barrier analysis.

2.2. Methodological approach

The research questions are already mentioned in the introduction section and are then detailed under the problem formulation section. Following the methodological approach, the whole analysis is comprised of these three kinds of corresponding variables: (1) Analysis of the current states of SMBEs (leads to the identification of critical state variables (2) Fleet and transportation states, barriers, and expected solutions (leads to the identification of critical fleet and transportation variables) (3) System level / operational states, barriers and support solutions (leads to the identification of critical operational variables). All these sets of variables will be further detailed in the conceptual model section.

The detailed steps of analysis followed as part of this methodological approach have been listed in the flowchart below. As shown in Fig. 1 (methodology flowchart step 1), the primary data source used in this analysis was obtained through self-conducted surveys, informal interviews, and on-site observations. However, secondary data was derived from open-ended questions and was used for detailed analysis in certain dimensions. Henceforth, data categories vary within multiple stages of analysis. A mix of qualitative and quantitative approaches was used. The qualitative data initially captured were based on a state and barrier analysis and a conceptual model of the problem. It was obtained through the use of open-ended survey questions, semi-structured interviews, public and private tours, and on-site observations. The quantitative data, based on state and barrier analysis and a conceptual model of the problem, are obtained using survey questions and on-site observations (statistical approach). At a later stage, the acquired qualitative data was further quantified to measure critical variables. The datasets were either descriptive (open-ended questions) or categorical (choice-based questions).

The rationale and the relevant assumptions necessary to ensure the validity and reliability of this research were carefully considered. A "negative risk" ethical approval was obtained prior to conducting the survey in logistics markets (Ref. No. ETH22–7079). The study was conducted with a group of approximately 75 respondents from various fresh produce retail markets across Sydney. A mix of qualitative and quantitative approaches was appropriate to ensure that the limitations of one type of data are balanced by the strengths of another. Using a mixed-methodology approach not only ensures the balance of strengths and weaknesses of each approach but also helps to cross-check the validity of data measures. More specifically, the qualitative methods (explained in the next section) used for data analysis help to ensure the 'construct validity' as well as the 'content validity' of the data. In parallel, the quantitative methods (explained in the next section) used for further data analysis help ensure 'criterion validity', which, upon passing, automatically triggers 'integrity and business rule validation'. Henceforth, 'Validity' was ensured through current market research, which took retail markets across Sydney as a case study and obtained proof of concept to evaluate stakeholders' needs in real-time scenarios. Additionally, reliability was ensured through the use of appropriate sampling methods and measures to mitigate the risk of a confidential information breach. There were no prominent biases detected in the data throughout the application of these validation checks as the anonymity of the respondents was thoroughly monitored.

2.3. Data collection

Qualitative Data: Referring to Fig. 1 again (methodology flowchart step 2), the data acquired in this research at the initial stage was descriptive and observatory in nature, which is based on the survey with key stakeholders of logistics SMBEs to understand the barriers being faced in going green. A state and Barrier Analysis (SBA) of the acquired information was conducted to prepare the conceptual model.

Quantitative Data: Firstly, to quantify survey results, weights and score ratings on a scale of 1–5 (1 being the least critical and 5 being the most vital factor) were assigned to the acquired dataset for identification of the most critical variables based on barriers that logistics SMBEs face when going green. Secondly, weighted and scored variables were manipulated using mathematical analysis to verify the conceptual model.

2.4. Analysis methods

2.4.1. Quantitative analysis

Sampling and Cleansing: Referring to Fig. 1 again, methodology flowchart step 3, data acquired with quantitative methods was prepared with sizable sampling and verification with the conceptual model to remove noise, false information, and outliers.

Descriptive Analytics and Statistical Testing: Statistical tests i.e.,

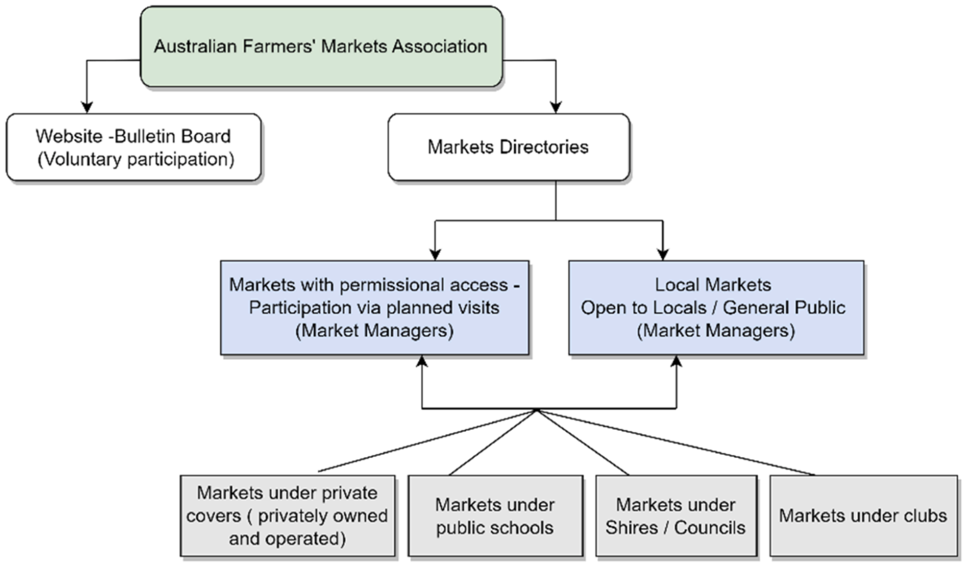

Fig. 2. Market segmentation for data collection.

frequency analysis (including Range, Minimum, Maximum), descriptive analysis (including Mean, Medium, Mode, Standard Error, Standard Deviation, Sample Variance, Kurtosis and Skewness) and mathematical modelling (including Friedman Test and Variables' Correlation graphs) were carried out to verify results.

2.4.2. Qualitative analysis

Content Analysis: In the first place, content analysis was performed to categorize and discuss the meaning of words, phrases and sentences written by the different participants in the survey for open-ended questions.

Thematic Analysis: Next, a thematic analysis was conducted, and

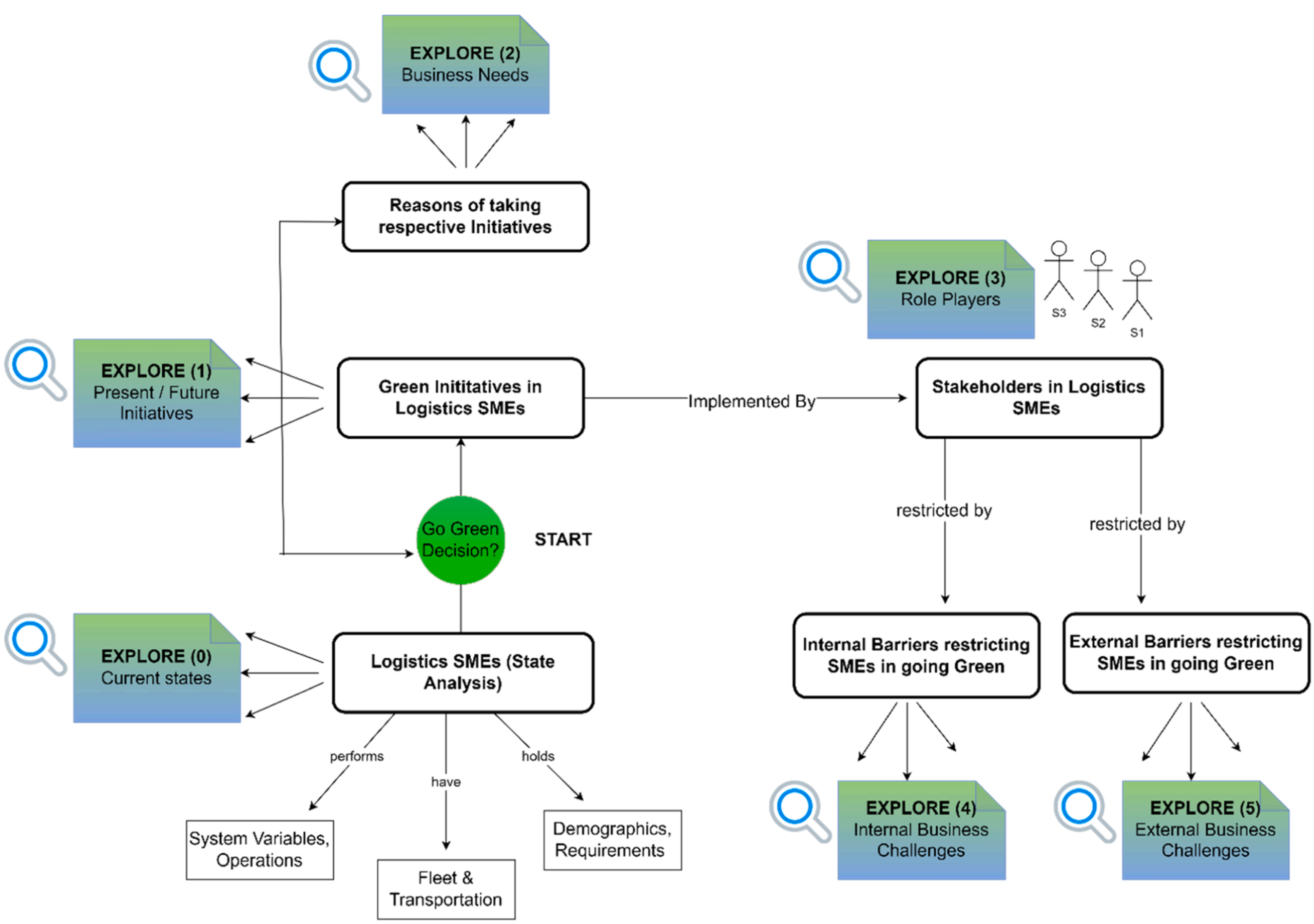

Fig. 3. Conceptual model of famer markets case study - high level.

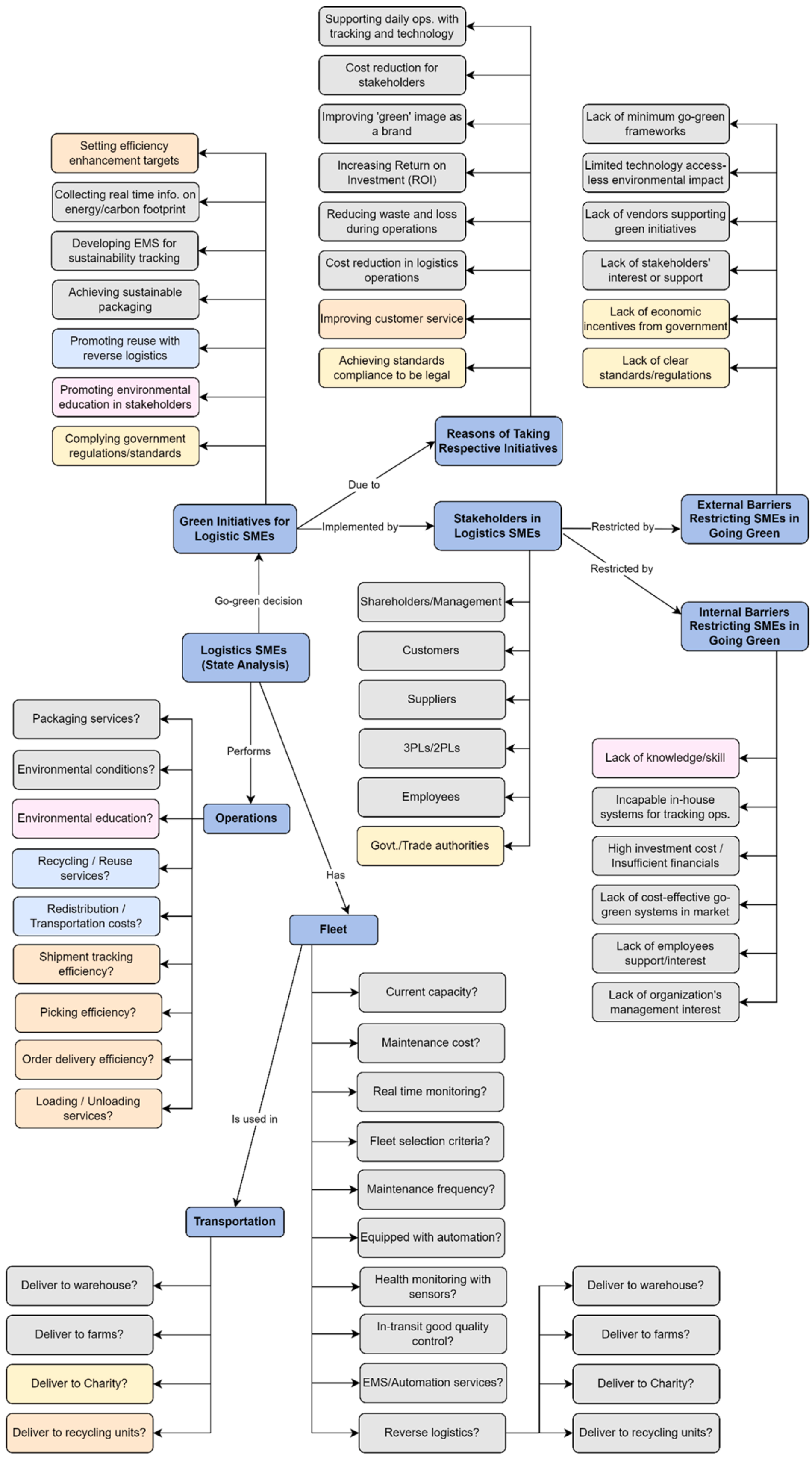

Fig. 4. Conceptual model of farmer markets case study - detailed level.

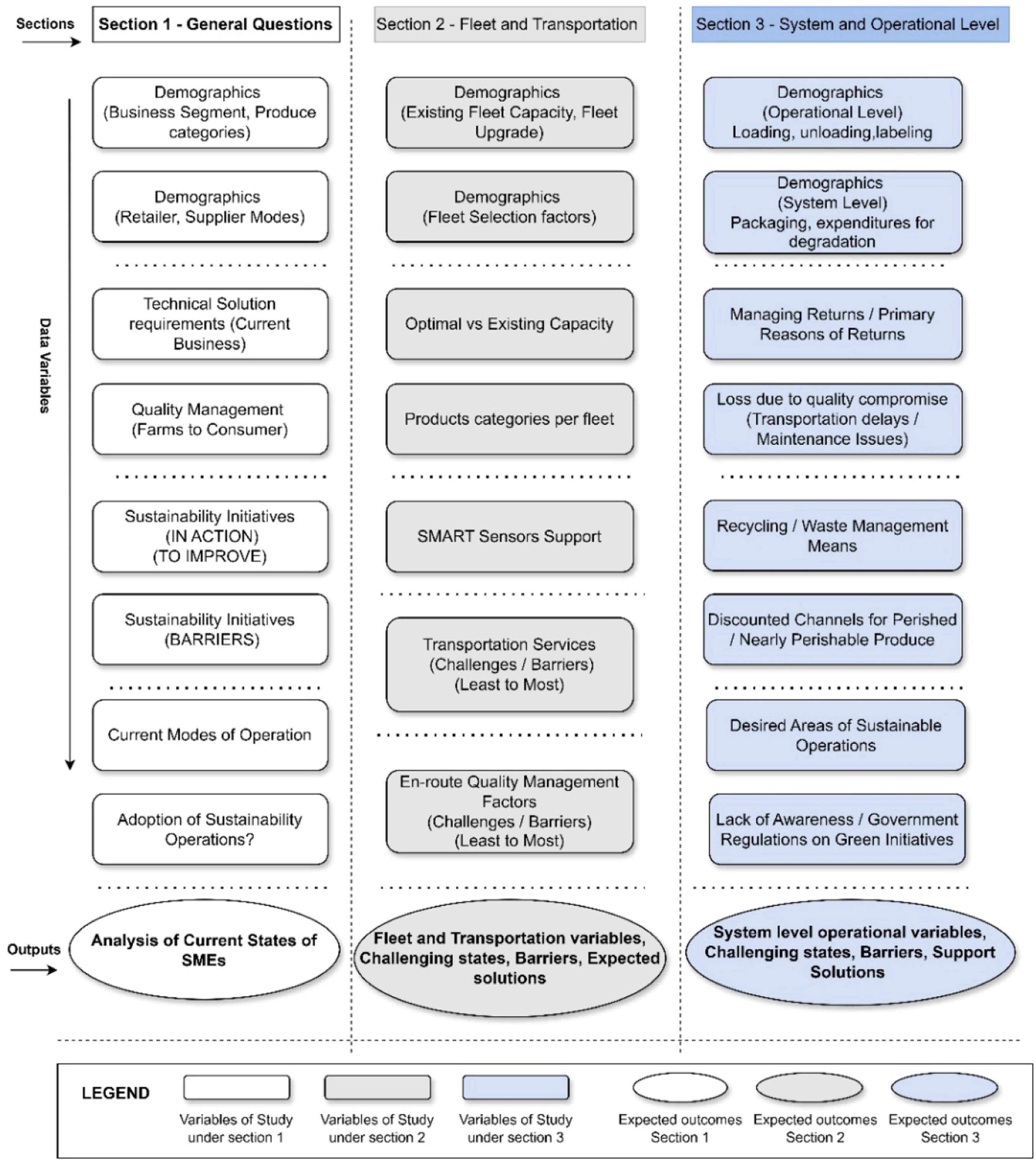

Fig. 5. Survey design – main outputs section wise.

the acquired data was closely examined to identify broad themes and patterns, within the descriptive text

2.5. *Justification of methodological choices*

Referring to Fig. 1 again, the methodology flowchart step 4, identifies two standard methodologies that are suitable according to the nature of the research phenomenon. As a mix of methods from these two standard methodologies was used for carrying out the analysis, there exist certain pros and cons of using mixed methods. Henceforth, there are already established strengths and limitations that were considered, and evaluation was carried out in different dimensions using branch analysis for each section of the survey and then holistic analysis out of all three sections by defining correlations and variable dependencies. This further provided us with a clear picture for testing the hypothesis and, hence, proving the results helpful in laying down the foundation for a design-level solution to the problem.

3. Market segmentation and conceptual model

Visiting different farmer markets and gathering the required data through on-site interviews and survey conduction proved to be a milestone for research progress, as well as the refinement of the research idea on practical grounds. A preliminary selection of markets was initially conducted from the list of available online markets. An in-depth analysis of the markets was conducted to define the market segmentation (Fig. 2), and the segments with the maximum number of potential stakeholders were selected to be visited. Due permissions were obtained where necessary. Farmer markets' managers were involved throughout the process to minimize the complexity of data collection as much as possible. Analysing the information gathered from on-site observations and short interviews, the conceptual model was designed (Fig. 2) to further support the multi-dimensional analysis.

The steps of analysis using the conceptual model include:

1. Analysing the current state of SMBEs using the dimensions of fleet, transportation, and operations, initially.
2. Green initiatives currently under consideration or already implemented by various SMBEs.
3. The relevant reasons behind each of those initiatives in step 2.
4. Stakeholders in logistics SMBEs that are involved in implementing those initiatives.
5. What internal barriers do stakeholders face when implementing these initiatives?
6. What external barriers do stakeholders face when implementing these initiatives?

The detailed conceptual model with sample states is listed in Fig. 4 to clarify the possibilities for the EXPLORE states mentioned in Fig. 3. These possibilities are not limited to those mentioned herein; they were further explored during the data collection process. To better understand this, Figs. 3 and 4 should be viewed in parallel, i.e., picking up a state in the conceptual model (Fig. 3) and then completing the cyclic trace analysis through several possibilities given in the detailed conceptual model (Fig. 4). For example, considering the operational states, "order processing efficiency" can be picked as a sample metric to understand the cycle. Assuming that it was ranked as low for a certain business, other operationally linked states (all in orange) can be traced and connected to that: i.e. overall order processing efficiency may be linked to the "low picking efficiency", "inefficient shipment/ order tracking," or even "slow loading/unloading service" effects. That is why "setting the efficiency enhancement targets" would be there in the green initiatives planned for any specific SMBE, and the corresponding reason behind this planned initiative could be to "improve the customer service". In this way, further examples can be traced out using the colour coding of the detailed conceptual model.

Collecting feedback from several SMBEs proved to be a significant milestone for this research in order to have an in-depth analysis of problems being encountered in going green. The successful completion of this milestone helped us further identify a minimal set of 'go-green variables' and would prove to be an initial step towards developing a go-green charter for SMBEs. Involving feedback from private or government agencies under which SMBEs operate and the connected clients of SMBEs proved to be a fruitful part of this research process. The expected high-level outcomes include (but are not limited to): 1. The identification of prime challenges faced by SMBEs who want to shift towards sustainable operations. 2. The justification of the need for a cost-effective lightweight enabler for green logistics data integration. 3. The validation of issues behind the lack of standardized benchmarks for operational sustainability parameters. These high-level outcomes were achieved via the compilation of results from different survey sections, deducing the critical variables and then validating the hypothesis against these critical variables.

4. Survey design and recruitment strategy

4.1. Survey design

The survey is titled "Fresh Produce Farming Businesses - Sustainability Practices, Problems, and Challenges." The survey was designed by dividing the questions into three sections, namely (1) General Questions, (2) Fleet and Transportation, and (3) System and Operational Level. The names are self-explanatory. Fig. 5 presents the sections and the main outputs (variables of concern) from each section.

The section on general questions primarily focuses on data collection regarding the current state of SMBEs. Collecting the basic demographics was important to define a proper market segmentation and focus specifically on those retailers whose participation and feedback could be fruitful to refine the problem itself. Therefore, Section 1 is a mix of close-ended and a couple of open-ended questions, covering business segments, produce categories, retailer-supplier modes, quality management and requirement of technical solutions in the perspective current state of operation. It also considers the willingness to adopt sustainable operations with respect to the sustainability initiatives already in action, as well as the needs for improvement and the barriers faced while implementing these initiatives.

As the name implies, the second section mainly focuses on fleet and transportation variables. Firstly, it captures the basic information regarding the existing fleet capacity, fleet upgrade plans, and fleet selection factors. Secondly, it explores whether the capacity ranges are at an optimal level with respect to the business needs or not. Also, is sensor level support available while the product is en-route or not? Finally, it explores the least to most challenging services with respect to the transportation (Inbound/outbound/leftovers management) and the most critical barriers in quality management of en-route produce. In this way, highlighting certain fleet and transportation variables in their challenging states and posing barriers, the output from this section provides proof of the concept regarding "what could be the expected solutions in daily business routines for challenging processes in action?"

Sections 1 and 2 together conduct dry runs of our conceptual model, as presented in Fig. 3. Section 3 primarily covers the operational aspects of daily business processes. The operational level demographics encompass loading and unloading facility levels, labelling, and packaging practices in action. Moreover, system-level information is also captured regarding the level of expenditures involved in managing degraded produce, among other aspects. Furthermore, the data on managing returns and the primary reasons for returns is also included. The existence of losses incurred due to quality compromises (Transportation delays, maintenance, and other issues) and the use of sensor equipment are also assessed. The presence of returns, waste management or recycling practices, and discounted channels for perishable or nearly perishable produce are analysed together holistically to test whether a key hypothesis is true. In connection with that, the desired areas of sustainability from an operational perspective are being inquired about. Finally, the lack of awareness and government regulations regarding green initiatives have been explored in the end. This section provides a holistic view of the challenges faced in daily operations from a sustainability perspective and the barriers encountered in implementing smooth, competitive business operations for these entrepreneurs.

4.2. Recruitment strategy

As the research was mainly based on the domain of Fresh Produce Logistics (FPL) for small-scale farming businesses, the research survey was designed to unfold the sustainability practices (in action or planned for future), set of problems and challenges faced by these small business owners. The survey was conducted in collaboration with an important

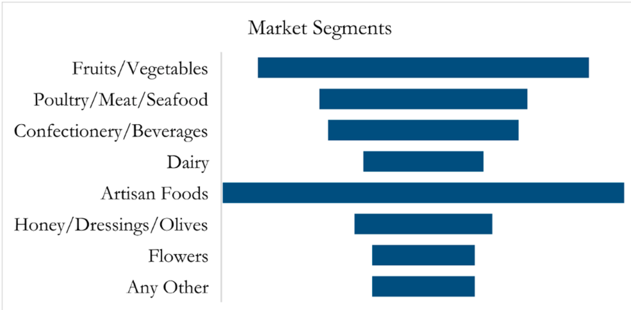

Fig. 6. Market segments.

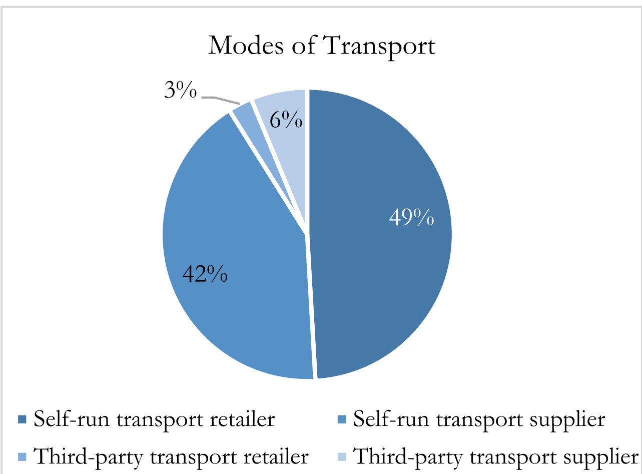

Fig. 7. Modes of transport.

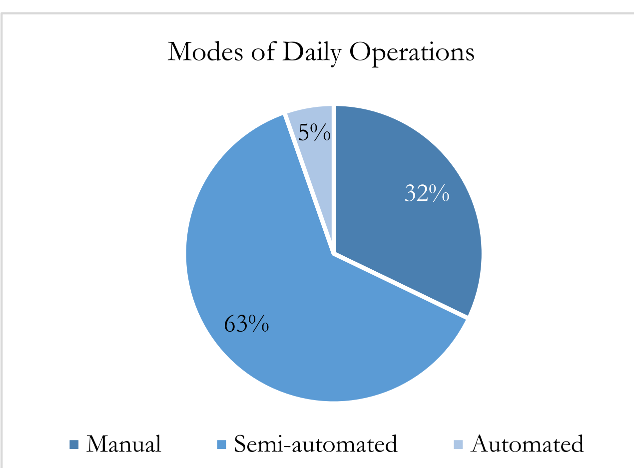

Fig. 8. Modes of daily operations.

stakeholder having mutual focus of concerns: "Sustainability, Fresh Produce Safety and Helping Small Businesses to Grow", namely Australian Farmer Markets Association (AFMA). The feedback from this stakeholder proved to be a significant value addition to this research survey design and its conduct. The researchers visited several markets across Australia to explore different sustainability practices in-action or planned for future, talking to the small-scale farmers and business owners to understand their problems; and exploring how can the researchers make it convenient for them to carry out their daily operations including transportation from farms/warehouses, orders management,

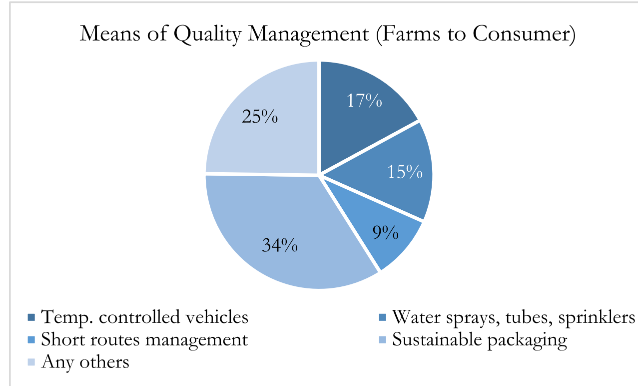

Fig. 9. Means of quality management.

packaging, and waste management.

5. Results

5.1. *Results – general demographics*

As mentioned previously, this section began with general questions and then followed the steps of the conceptual model through additional questions. The results obtained in this section test and validate our conceptual model, as defined previously in Section 5. As mentioned in the survey design, this study also aimed to include all the fresh produce segments that farmers deal with across different markets. Fig. 6 shows the different segments of this study that the respondents belong to. It can be seen that the highest number of respondents belong to artisan foods, which use fresh produce in their items, such as salads, tacos, pizzas, and wraps. The second highest category is fruits and vegetables, and the third highest is poultry/meat/seafood. Overall, all categories are part of our analysis because they are all ranked as fresh produce, either directly or indirectly, and are logistically part of the same cycle to reach the markets.

Figs. 7 and 8 present the modes of transport and modes of daily operations, respectively. It is evident form Fig. 7 that majority of the respondents under these markets are self-run logistic retailers as well as suppliers (being small to medium businesses) and Fig. 8 clearly shows that the mode daily of operations (including selling, order, delivery and packaging) for majority of the respondents is either manual or semi-automated. It means that the use of some applications was witnessed initially, in one way or another, for conducting the relevant daily operations listed above. This was further explored in detail, with more questions and additional analysis.

When asked about managing the quality of fresh produce from farms to consumer (Fig. 9), the maximum percentage of respondents rely on either sustainable packaging (34 %) or any other means (including ice boxes, coolers, special containers etc.) of temperature management (25 %) while the produce is en-route. Moreover, only 9 % are able to manage shorter routes (transport efficiency), which is the minimum overall. It also highlights the fact that route management is a considerable area for improvement. Also, only 17 % of the respondents attain the actual temperature-controlled vehicles for their en-route quality management, which is relatively low on average. This leads to the fact that the use of smart vehicles (with temperature control support) is not a common practice among small-scale farming businesses. Overall, various measures are in place to ensure quality management throughout the supply chain, from farms to consumers.

The next graphical results are related to each other as shown in two parts, Fig. 10(a) and (b). The respondents were asked about the support of any technical solution that their business currently needs to have a smooth operational execution. The answers varied in all dimensions of

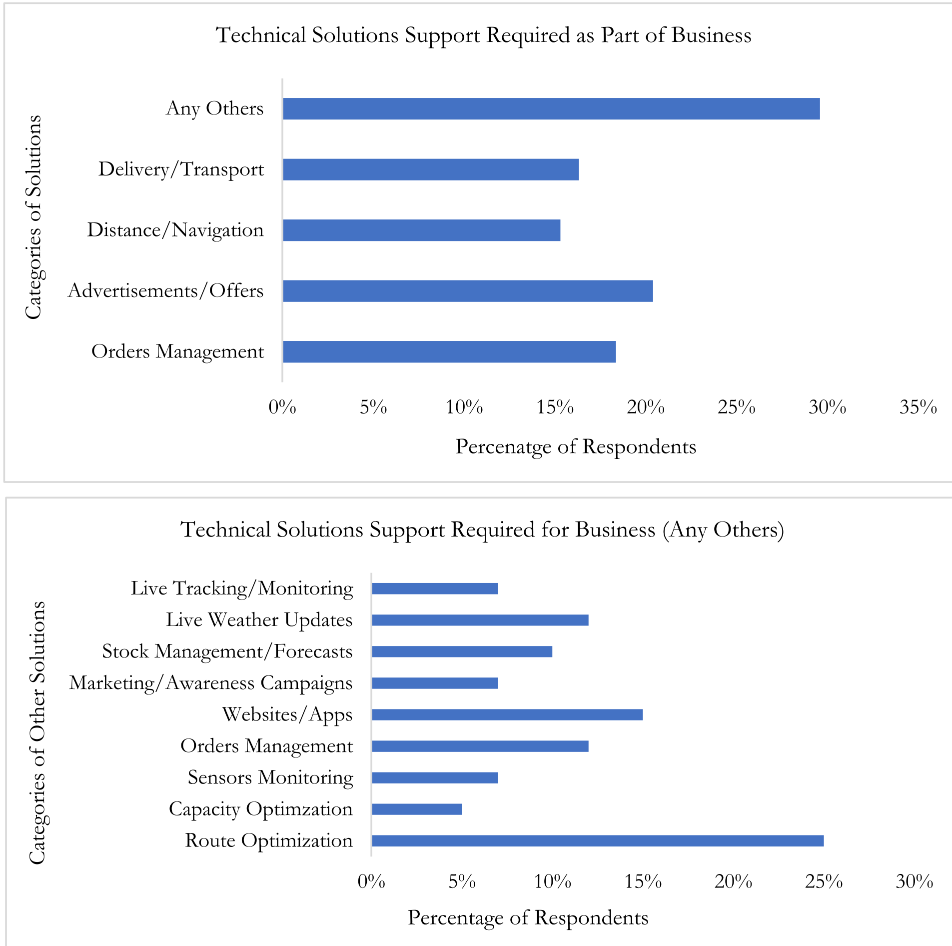

Fig. 10. Technical solutions required (a) as part of business, (b) any other.

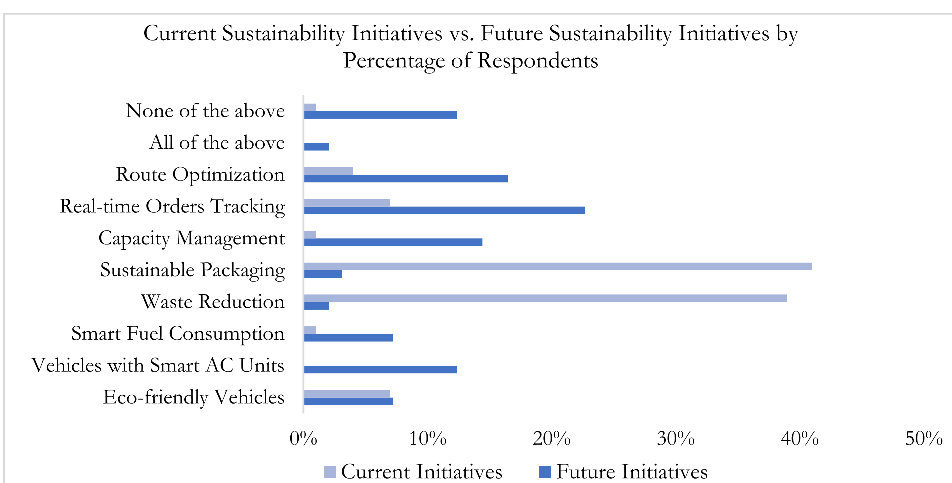

Fig. 11. Comparison of current vs. Future sustainability initiatives.

interest, including transport, navigation, orders, and advertising. Furthermore, we attempted to examine the details of the highest percentage in the "Any Other" category (30 %) in Fig. 10(a) and obtained the results as shown in Fig. 10(b). As depicted in Fig. 10(b), order management and related offers on orders fall into the second-highest category. At the same time, transport and navigation-related issues rank third, with a very narrow margin. This indicates that different categories of small-scale businesses are facing a variety of problems depending upon their produce and logistics category. Further exploring the top-most categories in Fig. 10(b), it indicates a variety of required technical solutions reported, among which 'route optimization' tops the list; online application support and integration support, live weather updates, and orders management-related issues are a few prominent ones to mention. As route optimization and order management are

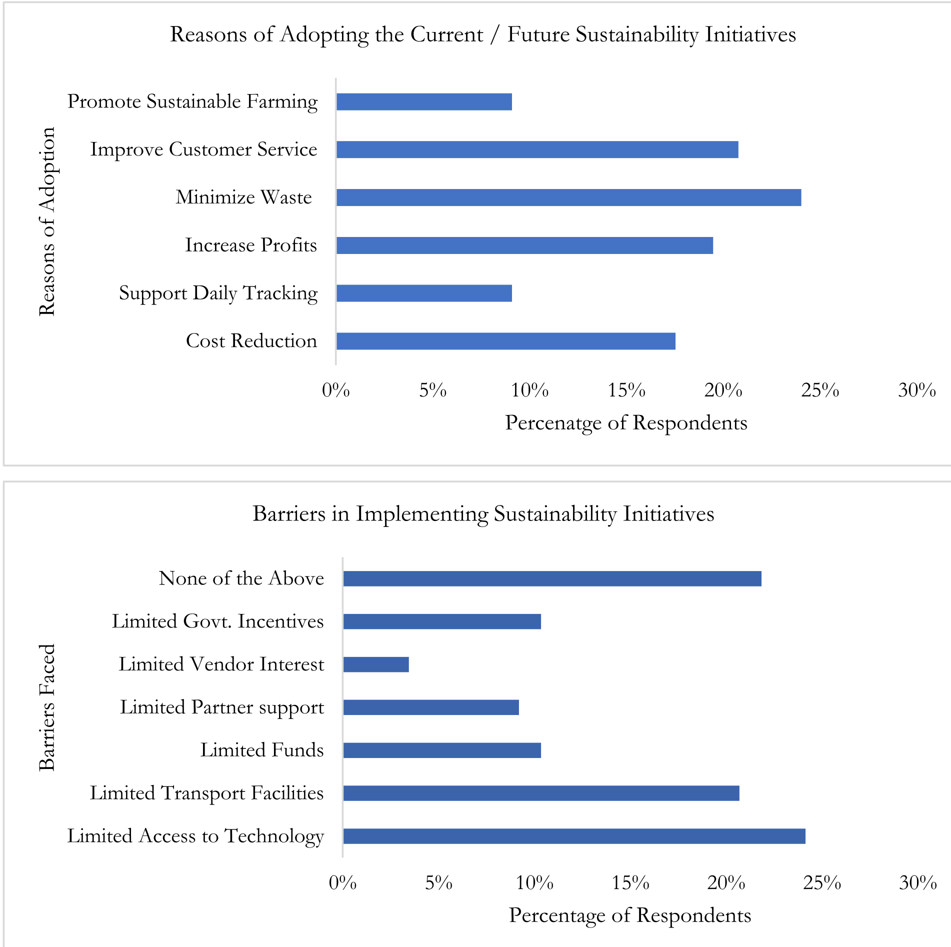

Fig. 12. (a) Reasons of adopting and (b) barriers in implementing sustainability initiatives.

correlated functionally, this is a clear indication of the transport-related problems while the produce is en route.

Fig. 11 presents a comparative analysis of current and future sustainability initiatives, highlighting areas that need improvement or implementation to ensure sustainable business practices. Several areas are future-planned and self-explanatory, indicating the needs of the businesses. It is evident from Fig. 11 that the majority of respondents are already utilizing sustainable packaging practices (42 %) for their produce and are also attempting to reduce waste through this approach (approximately 40 %). However, incorporating sustainable packaging is not the only means of waste reduction. That is why other waste reduction means were explored further in the subsequent sections. Among the other current initiatives, there is a negligibly low percentage of respondents implementing route optimization, real-time tracking, efficient capacity management, and fuel consumption. Similarly, the use of AC controlled is negligible (almost zero), which is a clear indication of the fact that these SMBEs are relying on other means of maintaining produce freshness. The use of environment friendly vehicles is also very low (only 7 %).

Fig. 12(a) presents the reasons behind the adoption of the current initiatives as well as the future planned ones. Additionally, Fig. 12(b) reports the barriers (problems) that respondents face while implementing current sustainability initiatives and, in parallel, the barriers they encounter in their planned initiatives for transitioning to sustainable practices. As evident from Fig. 12(a), the most significant reasons behind these implemented initiatives include "Cost reduction/ Increasing profits," "Improving customer service," and "Reducing waste" (ranging between 15 % and 20 %). Fig. 12(b) further elaborates the barriers behind implementing the initiatives where "Limited access to technology" (around 25 %) and "Limited transport facilities" (around 20 %) top the list. It clearly justifies the dire need of being operationally sustainable at the logistics level for these businesses and builds our case for further research explorations.

Table 1
Demographics - Fleet and transportation.

Demographic Factors of Study	Survey Statistics
Current fleet capacity	3–5 Trucks on average and optimal
Fleet upgrade undergoing?	NO or planned for future only
Fleet selection criteria?	Cost, Capacity, mostly ALL
In-Vehicle smart air conditioning	NO Smart air conditioning mostly
Product types loaded in fleet?	Mostly one type of products

5.2. Results - fleet and transportation

As indicated previously (in the survey design section), this section comprises questions on fleet and transportation-related issues, starting with a few simple questions that capture the current demographics of the respondents. The highlights of these demographics obtained, are listed in Table 1. Majority of the respondents have three to five trucks/ vans on average, indicating them to be small vendors, and fleet upgrades are mostly future planned. There is no smart AC support in the fleet most of the time, and only one type of product is transported at a time. Cost and capacity are the two most important factors affecting their choice of fleet selection. This is again a clear indication of limited availability of

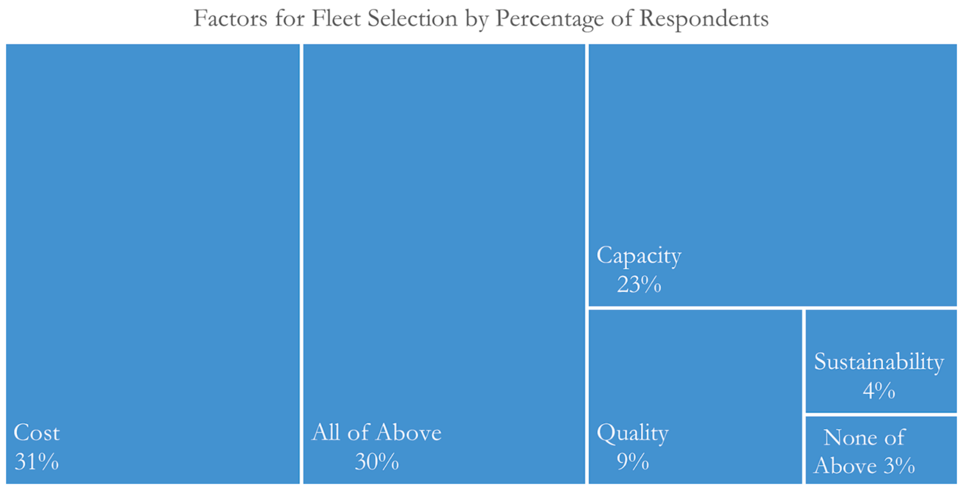

Fig. 13. Factors considered for fleet selection.

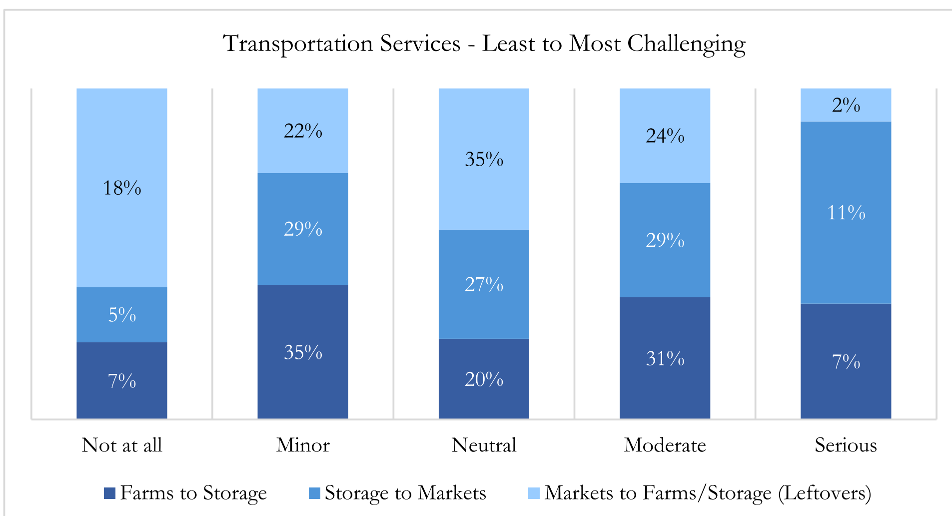

Fig. 14. Levels of transportation service.

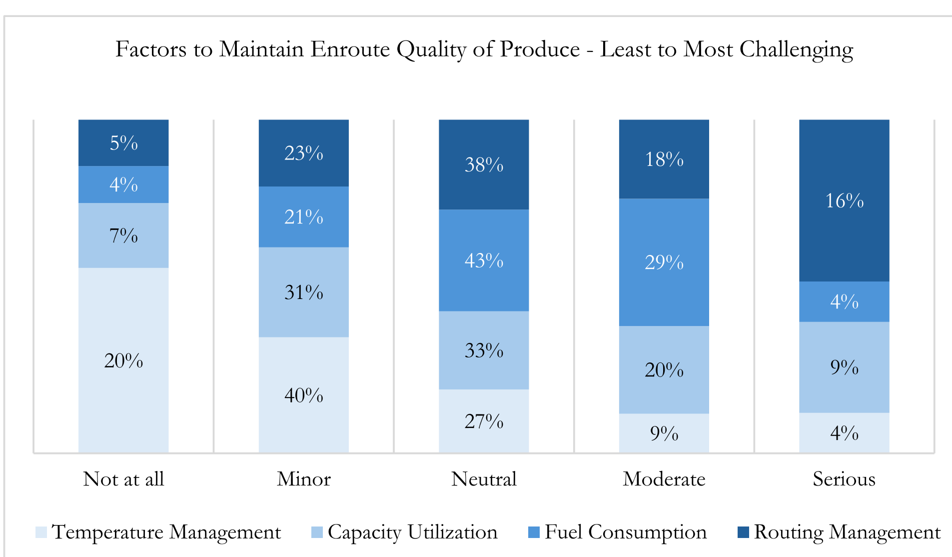

Fig. 15. Challenge levels for En-route quality maintenance.

Table 2
Demographics - System level and operational.

Demographic Factors of Study	Survey Statistics
Truck loading/unloading manual?	90 % manual
Satisfied with current packaging levels?	88 % satisfied
Auto-labelling service in practice?	30 % only
Degraded products returned?	70 % YES
Expense on managing degraded produce?	Medium – Circumstantial
Areas of desired sustainability levels?	Delivery Solutions, Vehicle Management
Lack of awareness of green initiatives?	50 % responded YES
Lack of govt. support in going green?	52 % responded YES

resources for small-scale businesses.

Furthermore, in this section, Fig. 13 illustrates the factors under consideration for fleet selection (in detail using the tree map), out of which cost and capacity tops the list. This indicates that businesses are facing capacity issues, and they either want to maximize the capacity of their existing fleet (avoiding the associated cost factor) or need to increase overall capacity by purchasing more fleets in the future.

Moreover, in this section, the respondents were asked to rank the levels of their current transportation services in action (from least to most challenging) from the perspective of waste generation. Therefore, each of the three transport services (Farm to Storage, Storage to Markets, and Markets back to Storage again) is ranked on a scale from least to most critical in terms of daily management. Results shown in Fig. 14 indicate transportation services are a moderate to serious challenge from markets to farms or storage (outbound logistics), accounting for the highest total of 29 % and 11 % in each category. Holistically, depending upon the produce category, efficient outbound transportation services remain a moderate to serious challenge for the majority of the respondents.

In connection to that, Fig. 15 shows the results of the critical factors affecting produce quality during transport (while the produce is en-route). The respondents were asked to rank them from the least to the most challenging factors. It can be seen in Fig. 15 that “fuel consumption” and “routing management” are among the most prominent factors to emerge as being critical, attaining the highest percentages among moderate to serious challenge levels – Fuel management being the highest (16 %) as a serious challenge and routes management being the highest (29 %) as a moderate challenge. Also, the majority of the respondents ranked “fuel consumption” as a challenge on a neutral basis, with the highest (43 %) indicating that it varies from case to case but still remains a fair challenge for most of the respondents. This strengthens the fact that transport (routes, fuel, logistics) are the challenging areas to deal with, when it comes to small-scale business with limited fleet resources and transport facilities.

5.3. Results – system and operational level

As indicated previously (in the survey design section), this section covers the aspects of operational and system-level variables under study, which are comprised of questions on operational issues. Like Section 2 of the survey design, the third section also begins with a few simple questions that capture the operational (system-level) demographics of the respondents. The highlights of these demographics obtained are listed in Table 2. As can be seen clearly, most of the daily operations, including loading, unloading, labelling, and packaging, are being handled manually by these businesses. Although, majority of the respondents are satisfied with their current packaging levels, still bearing extra expenses to manage degraded produce and returns which is an indicated area of loss being there, and consequently the desired areas of sustainability being reported by maximum respondent include vehicle management (fleet related issues) and delivery solutions (orders and transportation). This also emphasizes that the demographics listed here are in complete correlation with the results obtained in Sections 5.1 and

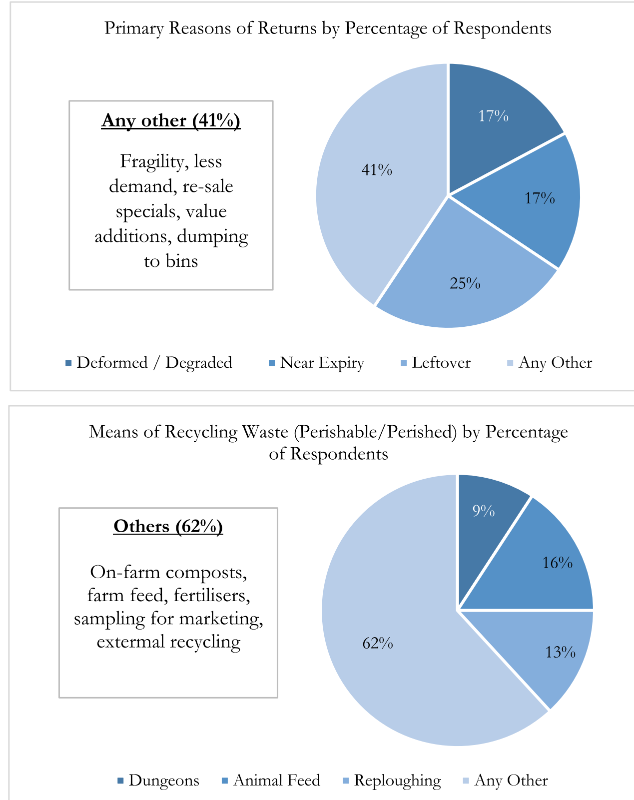

Fig. 16. (a) Primary reasons of return and (b) Means of recycling waste.

5.2. Lastly, there is a mixed response regarding the lack of awareness about ‘going green’ among small-scale farmers, as well as the lack of government support for small-scale businesses in adopting green practices. Exactly half of the respondents (50 %) agree with this lack of awareness and government support, while the rest think the opposite. Henceforth, there is a fair argument that improvements need to be made towards green initiatives for small-scale businesses and business owners.

Furthermore, this section examines the primary reasons behind returns, including whether reverse logistics are in operation or not, and the methods used for recycling waste. The primary reasons for returns are gauged in Fig. 16(a). There are diverse reasons accounting for the highest of 41 % in the “Any other” category, which was explored further in open-ended questions. The prominent ones include (but are not limited to) wastage due to fragility, lower turnout due to unpredictable weather conditions, reduced demand, returns for resale as market specials, and resale with value-added features (for example, using dairy to make on-the-go breakfast boxes, etc.). Majority of the respondents in this category, however, do not take returns, because of insufficient management resources at their end including the lack of proper recycling units on their farms, lack of connections with farmers having recycling units, deeming recycling to be costly in case of certain kinds of produce like fresh flowers, lack of connections to charity schemes, and others. That is why these SMBEs are often constrained to dump the leftovers directly into the bin at the end of the day. The second highest category (25 %) consists of the leftovers in general, and third highest categories (17 %) include near-expiry, deformed as well as degraded produce. In connection with this, various methods for recycling waste, including both nearly perishable and perishable materials, are explored, as shown in Fig. 16(b). The highest total (62 %) again contributes to a variety of recycling sources, which are further explored in an open-ended question. The prominent ones include (but are not limited to) sending to on-farm composts, converting into fertilizers or farm feed, selling at low costs to external recycling units, and sampling for marketing purposes. Recycling leftovers for animal feed and on-farm

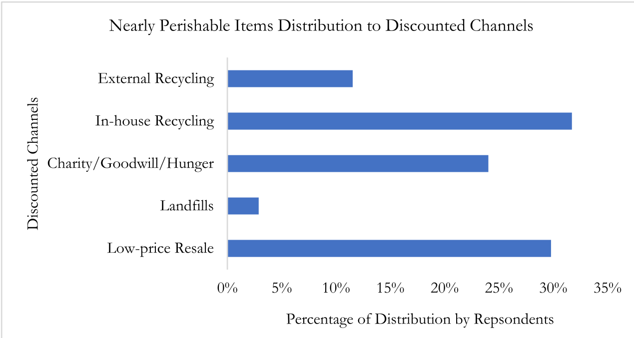

Fig. 17. Distribution to discounted channels.

reploughing are the second-highest categories with an average of 15 %. However, the use of dungeons is quite limited, accounting for only 9 %.

The recycling factor is further associated with the distribution of nearly perishable produce, whether in the form of returns or leftovers, across various discounted channels. That is why we have also investigated the leading distribution channels for nearly perishable and perishable produce, which are also essential to examine, as shown in Fig. 17. In-house (internal) recycling and low-price reselling are at the top of the list, with an average of around 31 %. Donating to hunger schemes, charity organizations, and as a gesture of goodwill to the community (friends, neighbours, the needy) also tops the list, with a total of around 25 %. However, the percentage of distribution or transportation to the external recycling units is low (11 %), which can be easily traced back to the fact that not every farm, has an internal recycling unit and sending it for the external recycling, involves a factor of cost, distance, time and transport factor. This helped to explore one of the primary research questions: where waste occurs across the logistics cycle, particularly in the absence of sufficient resources for SMBEs.

Fig. 18(a) and (b) indicates the absence of sensors and software integration with sensors, respectively. Fig. 18(a) indicates that most businesses have only temperature sensors deployed as part of their fleet (55 %), while the deployment of weight, vibration, and humidity sensors is at a negligible level, almost zero. All these sensors play a crucial role in the waste-free delivery cycle. Also, almost half of the total respondents (44 %) have no sensor deployments at all, which is clear evidence of the technological limitations these SMBEs are facing. Consequently, Fig. 18 (b) highlights the fact that there is the negligibly low percentage of tracking software integrated with these sensors mentioned above (only 2 %), and 88 % of the fleet have no sensor to software level integrations, which is an inevitable component of real-time tracking for the fresh produce logistics cycle. However, for only 9 % of the businesses, it is currently under planning to be deployed in future, which is again indicative of the fact that there are a very few businesses being aware of the importance of real time tracking and tracing solutions in this domain and looking to deploy cost effective solutions in future that could give them a competitive edge.

Finally, it ends by highlighting the areas of desired sustainability levels that enterprises want to achieve in their daily operations, in Fig. 19, i.e., “Delivery Solutions” (around 30 %) and “Fleet management” (around 18 %), which again connects back to the results of Section 2 (challenging areas for businesses). Additionally, most businesses (32 %) are seeking improvements in all areas of sustainability, including vehicle management, transportation, packaging, and overall delivery solutions, in the future. In total, it provides us with a picture of the pain points in the daily logistics cycle, as most respondents agreed to undergo planned transitions towards sustainable operations in the near future.

6. Mathematical formulations and validation

Holistically, based on a comprehensive data analysis across all sections, we have developed and mathematically formulated the following set of hypotheses, which is grounded in specific variables under consideration. In addition, the proposed hypothesis was supported using the null hypothesis H0 (Reverse case scenario) for each of the variables listed in the first column of Table 3, including capacity, route, temperature, manual controls, and returns. These variables serve as baselines for the analysis of critical factors and their associated barriers. The regression analysis was conducted using the available datasets from the survey results, and the summary of ANOVA statistics for all these variables is presented in Table 3. (The detailed results are available in the supplementary file provided.)

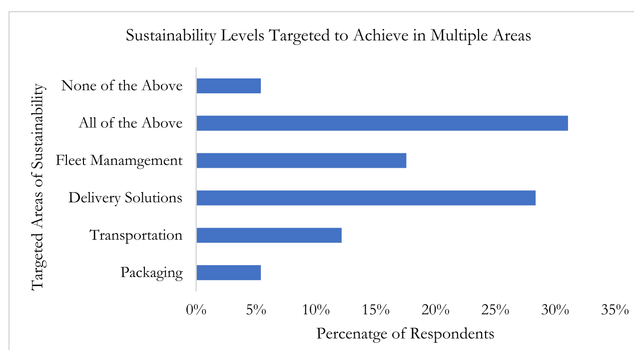

Fig. 19. Desired sustainability levels to improve/achieve.

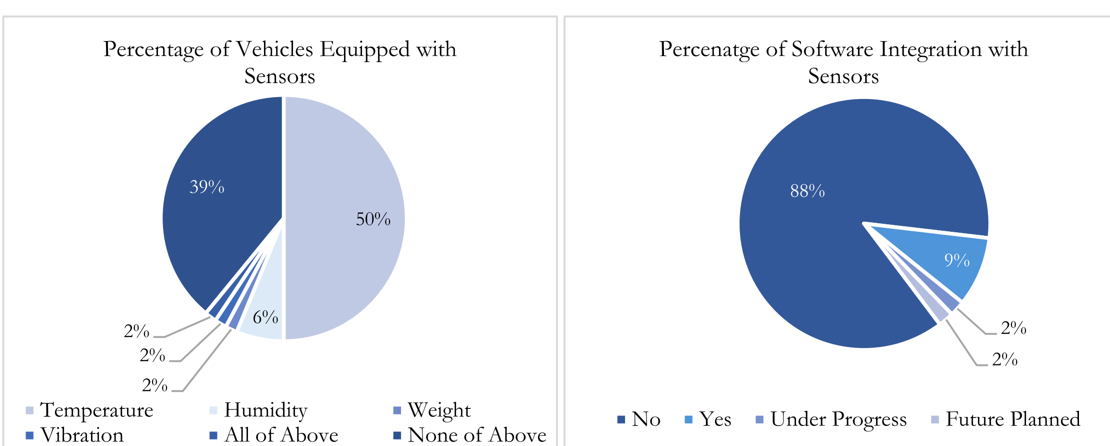

Fig. 18. (a) Vehicles with sensor equipment and (b) Software integration with sensors.

Table 3
Regression statistics for critical factor analysis.

Variables / Hypothesis	ANOVA Statistics	Coefficients	Standard Error	t Stat	P-value	Hypothesis by P-Values
Capacity Utilization (H1)	Intercept	1	0.6023	1.6602	0.1031	**Accept**
	Capacity Utilization Challenge (No)	1	0.6734	1.4849	0.1438	
	Capacity Utilization Challenge (Minor)	1.4118	0.6198	2.2778	0.0271	
	Capacity Utlization Challenge (Neutral)	1.6111	0.6188	2.6034	0.0121	
	Capacity Utilization Challenge (Mod.)	1.3636	0.6291	2.1675	0.0350	
	Capacity Utilization Challenge (Serious)	1.4	0.6598	2.1217	0.0388	
Temperature Management (H2)	Intercept	1	0.5921	1.6890	0.0974	**Accept**
	Temp Mgmt. Challenge (Not at all)	1.1818	0.6184	1.9111	0.0617	
	Temp Mgmt. Challenge (Minor)	1.3636	0.6054	2.2525	0.0287	
	Temp Mgmt. Challenge (Neutral)	1.6	0.6115	2.6166	0.0117	
	Temp Mgmt. Challenge (Moderate)	1.6	0.6486	2.4669	0.0171	
	Temp Mgmt. Challenge (Serious)	2	0.7251	2.7581	0.0081	
Routing Management (H3)	Intercept	2	0.2732	7.3211	1.69E-09	**Accept**
	Routing Mgmt. (Not at all)	0	0	65,535	0	
	Routing Mgmt. (Minor)	0.3846	0.3031	1.2691	0	
	Routing Mgmt. (Neutral)	0.6190	0.2920	2.1197	0.0389	
	Routing Mgmt. (Moderate)	0.5	0.3115	1.6053	0.1146	
	Routing Mgmt. (Serious)	0.8889	0.3154	2.8179	0.0069	
Manual Temperature Control (H4)	Intercept	2.5159	0.1956	12.8639	1.75E-17	**Accept**
	Auto-temperature controlled vehicles	0.0377	0.1490	0.2532	0.8012	
	Manual sprays, tubes, sprinklers	0.3099	0.1528	2.0283	0.0479	
	Short routes mgmt.	0.3043	0.1767	1.7224	0.0912	
	Sustainable Packaging	−0.0502	0.1550	−0.3239	0.7473	
	Any other	−0.1811	0.1410	−1.2848	0.2048	
Degraded Returns (H5)	Intercept	3.0392	0.1909	15.9189	4.79E-22	**Accept**
	Degraded Products Return	−0.3725	0.1381	−2.6973	0.0093	

6.1. Hypothesis 1: variable - capacity utilization

The first row of Table 3 presents the results based on P-values, ranking optimal capacity utilization from negligible to serious challenge. As can be seen from the results, the p-value is <0.5 ($P < 0.5$) across all categories, indicating a significant loss or waste during transport when fleet capacity utilization poses a serious to minor challenge (hypothesis H1). Henceforth, hypothesis H1 remains valid after the threshold level is satisfied, and the null hypothesis H0 (There is no significant loss or waste during transport when fleet capacity utilization is a serious to minor challenge) is rejected.

6.2. Hypothesis 2: variable - temperature control

The second row of Table 3 presents the results based on P-values, ranking the optimal temperature control from negligible to serious challenge. As can be seen from the results, the p-value is <0.5 ($P < 0.5$) across all categories, indicating a significant loss or waste during transport when fleet temperature management poses a serious to minor challenge (hypothesis H2). Henceforth, hypothesis H2 remains valid after the threshold level is satisfied, and the null hypothesis H0 (There is no significant loss or waste during transport when fleet temperature management is a serious to minor challenge) is rejected.

6.3. Hypothesis 3: variable - routing management

The third row of Table 3 presents the results, based on P-values, for optimal route management ranked on a scale from negligible to serious challenge. As can be seen from the results, the p-value is <0.5 ($P < 0.5$) across all categories, indicating a significant loss or waste during transport when fleet routing management poses a serious to minor challenge (hypothesis H3). Henceforth, hypothesis H3 remains valid after the threshold level is satisfied, and the null hypothesis H0 (There is no significant loss or waste during transport when fleet routing management is a serious to minor challenge) is rejected.

6.4. Hypothesis 4: variable - manual temperature control

The fourth row of Table 3 presents the results based on P-values for optimal route management, ranked on a scale from negligible to serious challenge. As can be clearly seen from the results, the p-value is <0.5 ($P < 0.5$) across all categories, indicating a significant relationship between loss or waste during transport and manual temperature control for managing fresh produce quality in transit (hypothesis H4). Henceforth, hypothesis H4 remains valid after the threshold level is satisfied, and the null hypothesis H0 (that there is no significant relationship between loss or waste during transport and manual temperature control to manage fresh produce quality in transit) is rejected.

6.5. Hypothesis 5: variable - quality control

The fifth and final row of Table 3 shows the results based on P-values for degraded products return, ranked on a scale from negligible to serious challenge. As can be seen from the results, the p-value is <0.5 ($P < 0.5$) across all categories, indicating a significant relationship between loss or waste during transport and whether the degraded products' return was in action or not. In other words, returns indicate product quality degradation during transit (hypothesis H5), which stands true from the p-value. Henceforth, hypothesis H5 remains valid after the threshold level is satisfied, and the null hypothesis H0 (that there is no significant relationship between loss or waste during transport and manual temperature control to manage fresh produce quality in transit) is rejected.

7. Proposed solution and implications

As can be seen from the survey results and the compiled regression statistics, certain variables and environmental factors are critical to the delivery of fresh produce. They become even more vital for farmers and small business entrepreneurs, given the limited resources they possess in terms of fleet, transportation, routing, temperature management, fleet and produce quality control, and certain other environmental factors. Furthermore, it is apparent from the above study that small to medium-sized business owners cannot afford state-of-the-art fleets equipped with

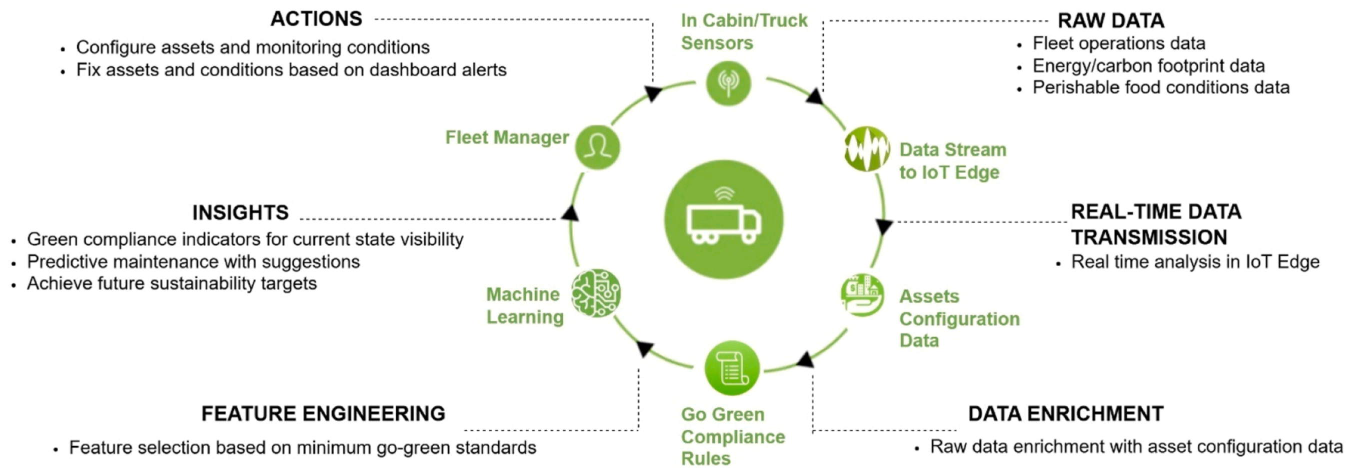

Fig. 20. Proposed sustainability eco-system.

modern automated tracking and tracing systems to manage and control the parameters stated above. The proposed solution centers on the fact that small business entrepreneurs can also transition to green operations by adopting low-cost, sensor-based (IoT) tracking and tracing solutions in real time with their existing fleet, focusing on minimal sensor integration and dashboard support. In this way, these businesses can utilize a simple, cost-effective solution for their daily logistics needs and become operationally sustainable by implementing a customized, need-based solution, thereby ensuring hassle-free deliveries and reducing waste in parallel.

7.1. The sustainability ecosystem as a cyclic solution

The sustainability ecosystem proposed as a design component of this research is a cyclical solution for logistics SMBEs that wish to go green by achieving their sustainability targets through optimized operations and information analysis, as displayed in Fig. 20 below. The proposed solution is based on six components that are integrated to work together holistically, helping the fleet manager conduct sustainable logistics operations through a prediction-prescription mechanism by sending dashboard alerts. The components primarily include a fleet manager with a condition-monitoring dashboard component, a real-time data transmission and streaming component, a data enrichment and asset management component, a standards-based feature engineering component, an insights-based predictive maintenance component, and an action recommender for improved asset-utilization component. Such a solution provides the flexibility to incorporate raw data management from various endpoints and sensor deployments, converting real-time data into actionable insights that enhance asset utilization and optimize operations, ultimately ensuring that the required sustainability targets are met. In this way, utilizing the proposed technology adoptions (within the cost constraints) can help alleviate the barriers (identified in the results section) for these SMBEs. The integrated working and roles of each of these components are discussed in the following section.

7.2. Sustainability eco-system – proposed components

Fleet Manager: The cycle begins with the role of the fleet manager, who configures a new trip, considering assets in action (vehicles), related information, and the type of perishable products being loaded. The fleet information must be configured at runtime via this customized dashboard, including capacities, route details, order details, and constraints, such as delivery time windows and order priorities.

In-cabin/Truck Sensors: When a vehicle leaves the bay, IoT devices transmit raw data related to the vehicle's route, environmental conditions for perishable food (e.g., cabin temperature and humidity measurements), and vehicle health data, including fuel consumption and CO_2 emission levels. Real-time tracking and tracing are required at this level, which can be achieved flexibly using any data streaming device, preferably an IoT edge device in this case.

Data Stream to IoT Edge: As the raw data stream gets enriched with asset-configuration data to make it more meaningful, this component comes into action. Raw data consists only of timestamps and specific event information, including temperature, speed, pressure, and AC levels, among other data points. That is why it is inevitable to make it insightful for further processing.

Assets Configuration Data: Then, after the data streaming device becomes active, the minimum go-green rulebook gets applied to achieve feature engineering over supplied datasets to evaluate the most critical factors, including frequent asset failures or food waste types under specific environmental conditions during transport, predictively.

Go-Green Compliance Rules: During this process, the unlabeled dataset with selected features for green compliance is fed into the machine learning algorithms to classify the percentage of greenness, i.e., the sustainability level of operations, as published by edge devices via the cloud, to display real-time compliance on the dashboard. In other words, the indicators (relevant KPIs) displayed on the dashboard indicate whether the desired levels of optimization have been achieved or not, continuously providing further preventive suggestions over time.

Machine Learning Algorithms: Subsequently, machine learning algorithms would be applied in parallel to historical batch datasets and barrier coefficients (pre-recorded by survey sample sets), which would learn from past failures and low sustainability scores to generate prioritized suggestions for adjusting the percentage values of non-compliance factors.

Iterative cycle: Finally, in a cyclic flow, the fleet manager would take corrective actions to fix key assets as indicated by the predictive and preventive dashboard suggestions. This enables operations to achieve sustainability by tweaking key assets or parameters, as suggested by the stakeholders.

7.3. Future works - reference architecture

Following the post-survey results, the design and architectural aspects of the proposed solution were mapped accordingly, incorporating the components and functionalities highlighted during the market analysis and as part of the survey results. The sustainability ecosystem discussed in the last section lays the foundation of the prototype system to be developed in the future for these SMBEs. It can be easily mapped to the physical architecture, as discussed in the section below. The process, however, is iterative, and the design level components can be incrementally refined further to achieve an initial prototype design. The

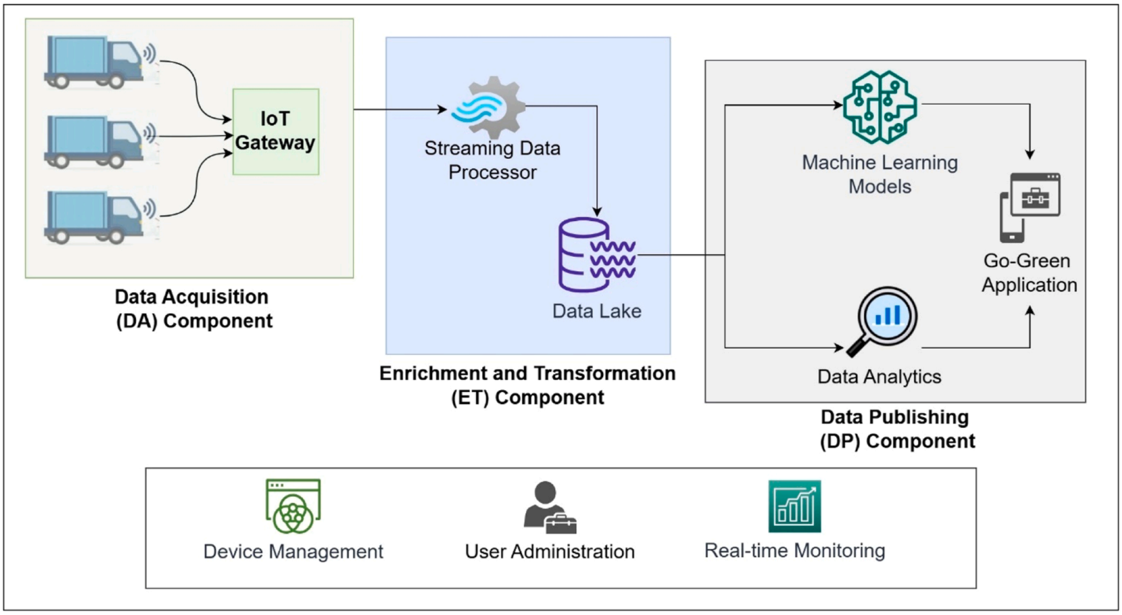

Fig. 21. Process view (Level 0) - reference architecture.

process view discussed below outlines the general flow of information across various components of the high-level system design, as illustrated in Fig. 21.

The reference architecture primarily consists of three components: Data Acquisition (DA), Enrichment and Transformation (ET), and Data Publishing (DP). Additionally, there are three support components for the overall support activities throughout, namely Device Management (which handles sensor setup within the fleet), User Administration (which handles views for managers and drivers), and Real-time Monitoring (which handles event triggers).

The overall working can be briefly explained as follows: SMBEs can register with the system using the Go-Green SMBE Application. Accordingly, the Fleet Manager for any registered SMBE can issue commands using the Application Programming Interface (API), connected via an IoT gateway, for fleet management. A customized dashboard for each manager, upon the trigger, will load the asset structure into the existing storage system of that SMBE. The raw data received from the DA component gets enriched with exported asset-structure data in the ET component. Then, the machine learning models integrate enriched data from multiple endpoints (data lakes) and transform it into useful green indicators via feature selection algorithms. After this integration is complete, the DP component displays these indications and suggestions on the user's managerial dashboard as a real-time data stream. Viewing this dashboard, the Fleet Manager can further analyse the situation and implement preventive measures as desired.

8. Conclusion

The survey findings, as discussed in the results implication section, provide a comprehensive barrier analysis for fresh produce retail markets. In connection with that, regression statistics and hypothesis testing further justify the critical factor analysis conducted, which strongly correlates each of these vital variables with the corresponding barriers. Finally, these identified barriers and critical variables lay the foundation for the proposed ecosystem-based cyclic solution, which caters to the desired needs of small businesses and clearly defines the opportunity mapping for these retail markets. Implementing this cyclic solution through reference frameworks would ultimately lead these businesses to become sustainable and become a waste-free stakeholder in the more intelligent supply chains for the fresh produce sector. Utilizing a low-cost, lightweight, and customizable solution for their daily needs would ultimately lead these SMBEs towards a path of sustainability.

CRediT authorship contribution statement

Maria Chaudhry: Writing – original draft, Visualization, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Faezeh Karimi:** Conceptualization, Methodology, Writing – review & editing, Supervision. **Kaveh Khalilpour:** Conceptualization, Methodology, Writing – review & editing, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.sftr.2025.100819.

Data availability

The data that has been used is confidential.

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