

TOWARDS A CIRCULAR ECONOMY FRAMEWORK FOR SME BAKERIES INTEGRATED WITH FARMING OPERATIONS

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ABSTRACT

SME bakeries face increasing pressure to improve sustainability while remaining competitive. Integrating farming and baking operations offers a pathway to achieve this by producing key ingredients on-site and reusing waste streams to close resource loops. However, designing such integrated systems is complex, requiring alignment between farm outputs, bakery demand, and circular economy principles. This study addresses these challenges by developing a Circular Economy Framework to guide the integration of farming and bakery processes. The framework highlights the interrelationships between production, waste reuse, and by-product transformation, offering SMEs a structured approach to balance environmental, economic, and operational goals. Grounded in the research onion paradigm, the study establishes the foundation for a future Circular Economy Decision Support System. Beyond improving efficiency and profitability, the framework contributes to food security and sustainable manufacturing practices, enabling SME bakeries to transition from survival strategies toward long-term resilience and competitiveness.

Keywords: SME, bakery, circular economy, decision support system, sustainability

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1 INTRODUCTION

A substantial segment of the global food industry is represented by baked goods, which indicates the global demand for baked goods. From breads and pastries to cookies, cakes, and confectionery, they significantly contribute to global food production, although specific percentages vary by region and product type [1]. The global consumption patterns are shaped by cultural traditions, economic conditions, dietary habits, and demographics [1]. For example, rising urbanisation and lifestyle changes have driven a demand for packaged baked goods such as breads and snacks [1]. Baked goods remain essential in meeting dietary preferences worldwide by holding a significant market share in the global food industry, despite the regional variations and diversity in products [1]. This highlights the need for further investigation into the broader impact of bakeries on society.

Bakeries generally operate under two main bakery business models, namely wholesale bakeries and retail bakeries [2]. Wholesale bakeries supply other businesses such as grocery stores, restaurants, cafés, and other food establishments by focusing on producing and distributing large quantities of baked goods [2]. In contrast, retail bakeries sell directly to the customer by offering freshly baked items such as bread, pastries, cookies, cakes, etc. [2]. Retail bakeries can take a variety of forms, including online bakeries that ship products nationwide, home bakeries operating from residential kitchens, bakery cafés offering a sit-down experience, mobile bakery food trucks, counter-service bakeries with small walk-in storefronts featuring a counter or bakery display case, etc. [2]. This paper focuses specifically on retail bakeries operating as small and medium-sized enterprises (SMEs).

The South African Department of Small Business Development defines a small and medium-sized enterprise (SME) as an independent business entity, together with its branches or subsidiaries and including cooperative enterprises, that can be managed by one or more owners and operates predominantly in any sector or subsector of the economy [3]. In accordance with the Standard Industrial Classification the criteria for a micro, small, and medium enterprise in the manufacturing sector are stated as micro having 0 to 10 employees with a total annual turnover of less than R7 million, small having 11 to 50 employees with a total annual turnover of less than R17 million, and medium having 51 to 250 employees with a total annual turnover of less than R170 million [3]. In South Africa, the number of SME bakeries increased following the deregulation of the baking subsector, which began in 1991 and removed requirements such as bakery registration and retail price controls [4]. These changes led many wholesale (industrial) bakeries to scale down, and created space for the growth of smaller bakeries [4].

To describe South Africa's bakery sector's profile, a detailed national industry survey that recorded employment by bakery type was conducted [4]. **Error! Reference source not found.** summarises the data. When comparing these results to the SME definition from the South African governmental document of 2019, it is evident that most baking enterprises in South Africa can be classified as SME bakeries since the majority have fewer than 250 employees.

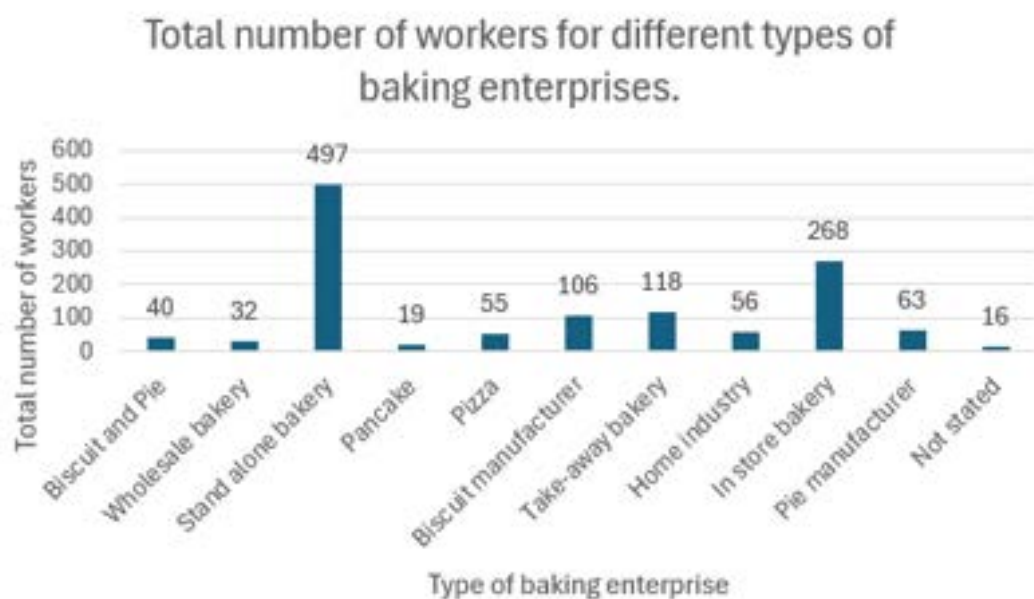


Figure 1: Total number of workers for different types of baking enterprises [4]

This shows a shift in focus from large wholesale bakeries to SME bakeries in South Africa. Furthermore, most entrepreneurs start their businesses as SMEs [5]. Thus, it is important to investigate SME bakeries, as this sector can create new opportunities for job creation and contribute to food security [4].

However, for SME bakeries to remain viable in the long term, these enterprises must not only contribute economically but should also address broader social and environmental responsibilities. This brings into focus the concept of organisational sustainability. Organisational sustainability can be understood as the organisation's contributions in supporting balanced sustainability in the economic, environmental, and social dimensions over various time periods, such as short-term and long-term periods [6]. This involves consistently embedding sustainability considerations into all the key areas of the organisation, including operations, strategic planning, internal systems, performance monitoring, etc. [6].

The concept of sustainability is commonly framed on three pillars, namely environmental, economic, and social [7]. The model typically implies a balance or trade-off between competing yet equally valued goals across these three categories [7]. The way an organisation manages these areas, as well as the pace and nature of the organisation's transformation efforts, plays a crucial role in shaping its sustainable performance [6]. Inputs, such as materials and resources that carry economic, environmental, and social implications, are converted into outputs, including products, services, and waste, all of which also hold value in those same dimensions [6]. The effectiveness of this conversion process is measured by how efficiently and responsibly the organisation uses its resources to achieve its objectives [6]. Furthermore, organisational sustainability is influenced by both tangible and intangible factors, such as infrastructure, workforce, cultural values, stakeholder relationships, and supply chain dynamics, each of which interacts to support or challenge the pursuit of long-term sustainability goals [6].

In the context of bakeries, core processes, such as mixing, baking, cooling and packaging, rely heavily on ovens, refrigeration units, and electric mixers, regardless of the variation in size and operation. These processes consume large amounts of energy, contributing to operational costs and environmental impact. Bakeries also generate various types of waste, including food waste from overproduction or unsold goods, as well as packaging materials. Food waste is seen

as a complex global problem that is increasingly drawing attention from both international and national scientific, professional, and policy-making communities [8]. Reducing food waste not only conserve valuable resources and lowers production costs, but it also serves as a meaningful way to promote responsible habits and attitudes toward waste reduction in future generations [8].

SME bakeries in South Africa face various challenges that restrict their ability to function effectively and efficiently. The 2002 study on the development of SME bakeries in South Africa used a survey to perform a SWOT analysis, determining the strengths, weaknesses, opportunities, and threats of this industry [4]. This study, presented in the current paper, focuses on the weaknesses and threats to identify the challenges SME bakeries face. The key weaknesses identified included high input costs, a lack of both technical baking skills and business and entrepreneurial skills, insufficient financial backup and support leading to cash flow problems, poor knowledge and understanding of market forces and product marketing, and a lack of confidence and business knowledge [4]. The key threats identified included competition that poses a significant risk to SME bakeries due to prevailing socio-economic circumstances, limited growth in the saturated South African baking industry, meaning that every new SME bakery could be taking an opportunity from another small, medium or large bakery, and the perceived high cost of ingredients compared to consumer price expectations [4].

Based on the challenges outlined above, it is evident that bakeries are struggling with both environmental and economic sustainability. Thus, the problem to be addressed is that SME bakeries struggle to achieve economic and environmental sustainability.

One potential solution lies in adopting circular economy (CE) principles. The circular economy is a regenerative economic system emphasising a fundamental paradigm shift to replace the traditional end-of-life concept with strategies focused on reducing, reusing and recycling materials throughout the supply chain [9]. The aim is to promote value maintenance and sustainable development, which creates environmental quality, economic development, and social equity to the benefit of the current and future generations [9].

Figure 2: Graphical representation of the circular economy (CE) definition [9] provides a graphical representation of this circular economy definition.

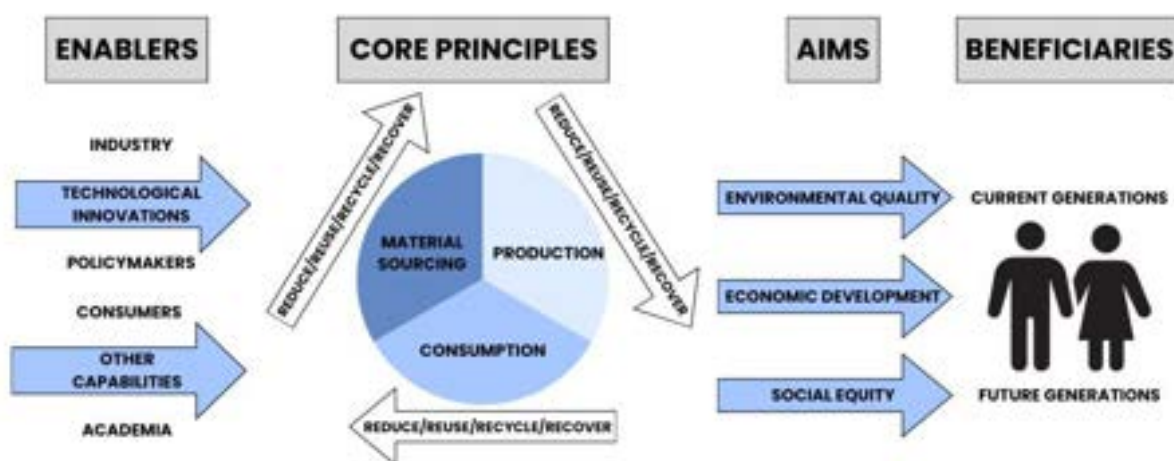


Figure 2: Graphical representation of the circular economy (CE) definition [9]

SME bakeries can greatly benefit from circular economy practices, which aim to reduce waste and pollution, keep materials in use for as long as possible, and restore natural systems. A potential solution to address the economic and environmental sustainability challenges of SME

bakeries lies in integrating a smallholding farm with an SME bakery. This could enable the development of a more sustainable bakery-food system by optimising resource use, shortening supply chains, reducing food loss and waste, and promoting sustainable practices across the production, processing, distribution, and consumption stages [10]. Globally, agricultural waste is generated daily from sources such as crop residues, agro-industries, livestock, and aquaculture [11]. Smallholding farms with livestock, crops, aquaculture, etc., also generate agricultural waste that is often underutilised. Bakery waste can be used in several valuable ways. Such as, turning it into bioethanol, a type of renewable energy, which can be used to power farm operations and reduce the use of fossil fuels [12]. Bakery by-products can also be used as animal feed, thereby lowering feed costs, maintaining animal health and performance, and reducing environmental harm ([13];[14]). In addition, the use of proper tracking systems helps ensure food safety and builds trust in circular food systems. Some studies have shown how food waste from onions and tomatoes can be added to bread without affecting its taste or quality. These ingredients improve the bread's health value and create new income opportunities for small producers ([15];[16]). These examples show that circular economy solutions are practical, low-cost, and suitable for smallholder farms. Since both bakeries and farms generate waste, this integration could be further strengthened through a circular economy whereby the bakery waste and the farm waste are repurposed for the farm and in return, the farm supplies the bakery with selected ingredients that are feasible to produce locally. Instead of relying on ingredients brought in from suppliers, baking and farming processes can be integrated to produce essential materials such as grains, dairy, eggs, and oilseeds. Waste from both farming and baking processes can then be reused within the system, helping to close the loop and reduce environmental impact as well as promote economic performance.

However, starting an SME bakery integrated with farming processes is complex. The system design must ensure that customer demands are met while effectively aligning farm outputs with bakery production, all within a framework of sustainability and profitability. This involves determining what can feasibly be produced on the farm, identifying which waste streams are suitable for reuse, and deciding how they can be transformed into valuable by-products to support a circular economy. It also requires evaluating and selecting the most beneficial uses for these by-products. Without practical decision support systems (DSS), SME bakeries often lack the knowledge and guidelines needed to implement such an integrated system successfully. However, before a DSS can be designed, a framework is required, indicating the different elements and the interrelationships between them.

Therefore, this study aims to design an SME bakeries circular economy framework (SME-CE framework) for integrating farming and baking processes.

Future research will then be able to use the CE framework to design a complete circular economy decision support system (CE-DSS) for integrating bakery and farming processes.

2 NARRATIVE LITERATURE REVIEW

2.1 Circular economy

The circular economy is much broader than just the definition provided in Section 1 and will be further investigated in this section. Although the circular economy now encompasses more than the original 3Rs, it is still fundamentally governed by the three core principles of reduce, reuse, and recycle [17]. These 3Rs are also promoted by the Ellen MacArthur Foundation, which developed the ReSOLVE framework to provide guidelines for implementing circular economy principles [18]. This framework was initially designed to target business strategies, but it consists of a versatile structure that applies to many sectors [18]. Although its application within agricultural systems remains relatively limited, it holds significant potential in the context of food system sustainability [18]. In agriculture, there is a growing emphasis

on transitioning from high-output, low-efficiency operations toward processes that prioritise nutrient recycling and closed-loop systems [18].

Error! Reference source not found. illustrates the principles of the ReSOLVE framework, along with the objective of each of the principles [18]. These principles will serve as the design requirements to ensure that the circular economy concepts are applied to the design of the framework.

Table 1: The circular economy principles of the ReSOLVE framework [18]

ReSOLVE framework		
Symbol	ReSOLVE principle	Objective
R	Regenerate	Implement active recovery, the use of green technology, and the preservation of already-existing natural spaces to maintain and repair the health of natural ecosystems.
S	Share	Reduce the demand for individually owned products through product-sharing.
O	Optimise	Increase efficiency in production processes by cutting away unnecessary waste.
L	Loop	Valorise end-of-life waste products by reusing and upcycling.
V	Virtualise	Develop and adopt virtual technologies to replace wasteful processes, where possible.
E	Exchange	Shift towards purchasing more sustainable and longer-lasting products when replacing products at the end of their life.

2.2 Bakery product categories

Baked goods can be classified based on various factors, such as the ingredients used, texture, production methods, etc. In the book, *Baking Problems Solved*, the baked goods are grouped into categories, namely bread and other fermented products; cakes, sponges and muffins; biscuits, cookies, crackers and wafers; and pastries [19]. This classification helps to distinguish between the unique characteristics of each type of baked product. This classification will be used in the first phase of designing the framework.

2.3 WWF Terrestrial Ecoregions

The world can be categorised from different perspectives, such as land, aerial or aquatic. When focusing specifically on terrestrial landscapes, the most recent and widely accepted framework is the Terrestrial Ecoregions model developed by the WWF's Global 200 initiative. This model presents a globally consistent framework of 867 terrestrial ecoregions [20].

Although the intended purpose was to guide conservation efforts, these ecoregions were defined through the collaborative work of over 1000 experts, including biogeographers, taxonomists, conservation biologists, and ecologists worldwide, based on the foundation of classical biogeography [20].

Ecoregions are relatively large land areas characterised by a distinct assemblage of natural communities and species, with boundaries approximating the original extent before significant human-driven land-use change [20]. The WWF terrestrial ecoregions map provides a comprehensive global and regional coverage [20]. It builds on existing biogeographic knowledge and reflects the distribution of a range of diverse fauna and flora [20]. Ecoregions are classified within a system of biogeographic realms and biomes [20]. The combination of classifying ecoregions into 14 biomes and eight biogeographical realms allows for meaningful comparisons between regions and facilitates the identification of representative habitats and species groups [20].

Figure 3 illustrates the WWF terrestrial ecoregions map with the eight biogeographical realms as Oceania, Nearctic, Neotropic, Antarctic, Palearctic, Afrotropic, Indo-Malay, and Australasia

as well as the 14 biomes listed as tropical and subtropical moist broadleaf forests; tropical and subtropical dry broadleaf forests; tropical and subtropical coniferous forests; temperate broadleaf and mixed forests; temperate coniferous forest; boreal forests or taiga, tropical and subtropical grasslands; savannas and shrublands; temperate grasslands, savannas and shrublands; flooded grasslands and savannas; montane grasslands and shrublands; tundra; mediterranean forests, woodlands and scrubs; deserts and xeric shrublands; mangroves [20].

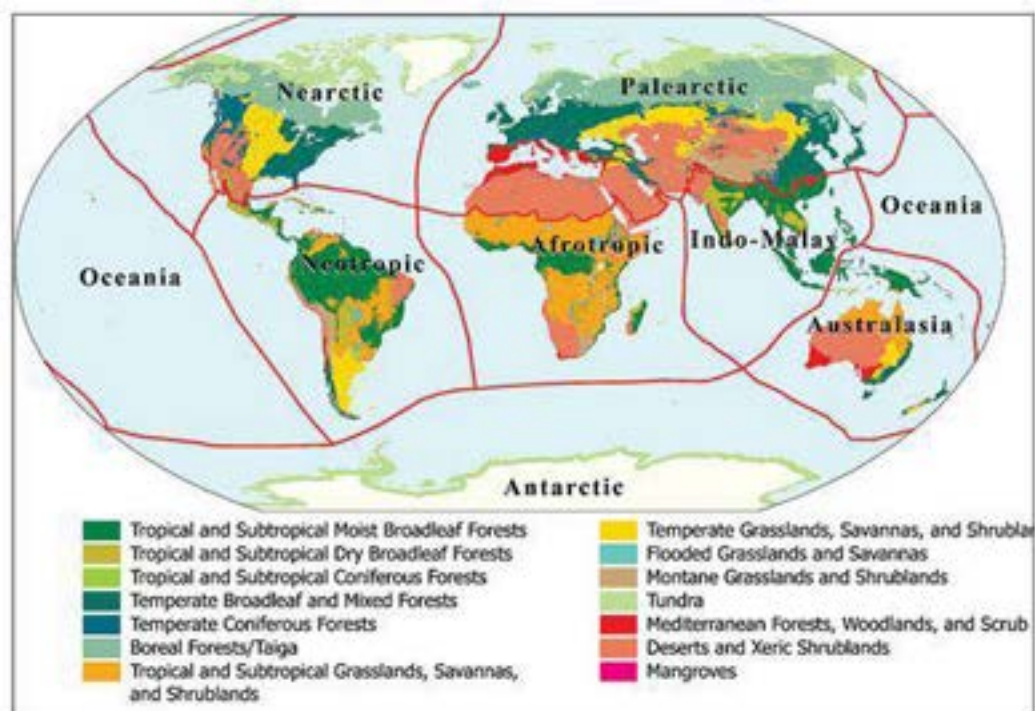


Figure 3: The WWF terrestrial ecoregions map [20]

These 14 biomes of the WWF terrestrial ecoregions will be used in the second phase of designing the CE framework.

3 METHOD

The method section of this study is divided into two subsections, namely the research paradigm, which guided the study, as well as the research method, which details the different phases the study followed.

3.1 Research paradigm

The research onion paradigm was adopted for this study and contextualises the research process through six layers, each representing a step that progresses from the outer layer inwards [21]. These layers guide researchers through a structured approach, from the initial philosophical stage to the final data collection techniques [21]. Figure 4 visually presents the research onion methodology by highlighting each of the six layers together with the possible choices for each layer.

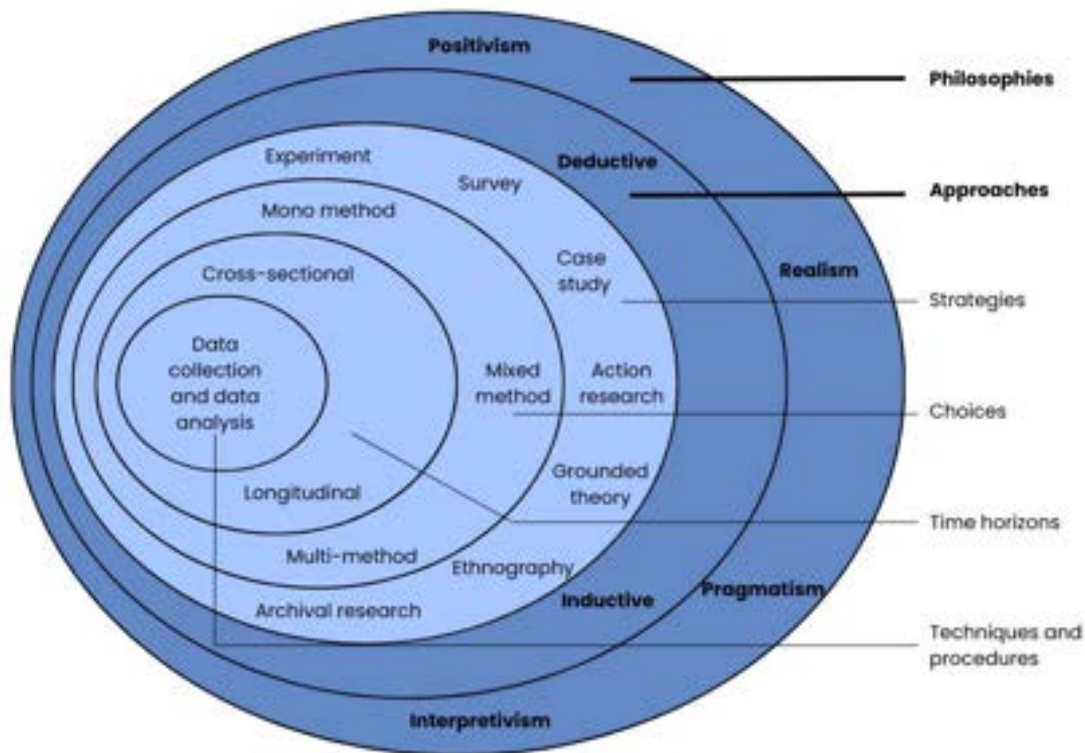


Figure 4: Illustration of the research onion methodology [22]

3.1.1 Research philosophy

This study adopted pragmatism as the research philosophy, as it aimed to design a practical CE framework for SME bakeries based on the insights gathered from literature. Pragmatism is guided by the principle of choosing methods and perspectives that best answer the research question, rather than being confined to a single philosophical stance [22].

The three elements that form the foundation of selecting a research philosophy include ontology, epistemology, and axiology, which influence how research is approached and conducted. Each of these is discussed in the context of pragmatism to justify the selection for this study. Ontology refers to the nature of reality from the researcher's perspective [22]. From a pragmatic perspective, reality is seen as external and multiple, with the view selected based on what best enables answering the research question [22]. Epistemology refers to what is seen as acceptable knowledge from the researcher's perspective [22]. Pragmatism accepts either or both observable phenomena and subjective meanings as sources of credible knowledge, dependent upon the research question [22]. It focuses on practical, applied research by integrating different perspectives to interpret the findings [22]. Axiology refers to the role of values in research from the researcher's perspective [22]. Under pragmatism, researchers values play a key role in interpreting results, where both objective and subjective viewpoints are considered valid [22].

The emphasis lies in the usefulness and applicability of the CE framework to SME bakeries, which aligns strongly with the pragmatic focus on real-world solutions. By adopting a pragmatic worldview, this study remains open to various forms of knowledge and prioritises practical outcomes. The goal is not only to understand current CE practices in theory, but to design a CE framework that can be implemented in real-world SME bakery operations, making pragmatism the most suitable philosophical approach for this study.

3.1.2 Research approach

An inductive research approach was applied to this study as it aimed to design a CE framework for SME bakeries by identifying patterns and insights from qualitative data, rather than testing an existing hypothesis [22].

An inductive research approach requires a close understanding of the research context, involves the collection of qualitative data, offers flexibility to adapt and refine the focus of the study as new insights are identified, and requires the researcher to play an active role in interpreting the data and shaping the outcome [22].

In this study, a close understanding of the challenges faced by SME bakeries and the application of the circular economy to SME bakeries was required to design the proposed CE framework successfully. Therefore, the inductive research approach aligns with the goal of this study to design a practical model based on the qualitative knowledge found in the literature.

3.1.3 Research strategy

Action research focuses on research in action to collaboratively address organisational challenges in partnership with those directly involved [22]. Thus, this study adopted an action research strategy, as it focused on research in action to address organisational challenges, specifically the economic and environmental sustainability challenges of SME bakeries, by providing a feasible solution. The process followed an iterative action research cycle by looping between reviewing literature to inform the design, progressing with the design until new information needs are identified, and then returning to the literature again to gather the required insights. This cycle was repeated as necessary. Since this study aimed to integrate available literature on circular economy applied to SME bakeries integrated with farming operations, this strategy offered flexibility and creativity to identify and establish the relationships and patterns in the literature with the design of the CE framework.

3.1.4 Methodological choice

A methodological choice was made to use a monomethod with the collection and analysis of qualitative data in this study. A mono method refers to using a single data collection technique and a corresponding analysis procedure [22]. This study only used qualitative data collected from literature, where qualitative refers to any data collection technique or data analysis procedure that generates non-numeric data [22].

3.1.5 Time horizon

The time horizon for this study was chosen as cross-sectional, as it was the study of a particular phenomenon, namely the circular economy in SME bakeries, at a particular time [22].

3.1.6 Data techniques and procedures

Data collection and analysis techniques included searching for relevant literature through the Scopus database and Google Scholar by means of an iterative narrative literature review to develop the design requirements and to inform the design phase of the CE framework.

3.2 Research phases

The research phases represent the three phases of the study. Table 2 explains the research phases by referring to the objective for each phase.

Table 2: Research phases

Research phases		
Phase	Description	Objective
1	Narrative literature review	- Identify the gap and support the problem. - Collect data on circular economy, biomes, bakery categories, etc. - Develop design requirements for the CE framework.
2	CE framework design	- Integrate the collected data. - Design a CE framework.
3	CE framework verification	Ensure that the CE framework complies with the design requirements.

4 DESIGN

As stated previously, it is evident that bakeries place significant strain on both environmental and economic sustainability. However, starting an SME bakery integrated with farming processes to support economic and environmental sustainability is complex and without practical decision support systems, SME bakeries often lack the knowledge and guidelines needed to implement such an integrated system successfully. Thus, the CE framework was designed towards assisting bakery owners in successfully identifying and aligning potential farming and bakery processes.

4.1 Design requirements

The ReSOLVE principles were developed by the Ellen MacArthur Foundation, as outlined in Table 1. These are adopted as the design requirements to guide the integration of CE principles into the framework. To ensure relevance and practicality, only those ReSOLVE principles that align with the specific phase of the CE framework will be applied during the design process.

4.2 Designing the framework

The CE framework was designed in phases to accommodate its subsystems. At this stage, it consists of three subsystems, each designed in a separate phase. For the purpose of this paper, only the first two phases are completed, while future research will address the remaining phase. Phase 1 focuses on the bakery component of the CE framework, while Phase 2 addresses the farm component. Phase 3, which will be developed in future work, aims to integrate the farm and bakery processes through a decision support system. This system will allow users to input available space and generate balanced configurations of farm and bakery operations. For example, it will provide guidance on the appropriate ratios between livestock (e.g., cows and chickens), crop production, and bakery capacity to ensure that the overall system design is feasible and aligned with spatial and operational constraints.

4.2.1 Phase 1

The first phase of designing the framework was classifying the products produced in the bakery. In Section 2.2, the different bakery product categories were listed.

4.2.2 Phase 2

The first part of the second phase of designing the framework was presenting global biomes to classify the region in which a bakery is located, considering factors such as climate and growing patterns.

The second part of phase 2 used this information in combination with the bakery product categories of the first phase. For each category, the most-used ingredients were determined through a sampling method involving five randomly selected recipes per category. An ingredient was considered frequently used if it occurred in at least three out of five recipes. For example, within the "breads" category, the sample recipes included white and brown bread (representing basic yeast-leavened bread), sourdough bread (representing artisan rustic

bread), brioche (representing enriched bread containing fat, sugar or eggs), and pita bread (representing flatbread). This approach ensured that a diverse range of sub-categories were captured when identifying the most-used ingredients within each primary category. Ingredients were then classified according to the biomes in which they can grow or thrive. The system distinguished ingredients and by-products that can feasibly be produced on a smallholding farm from those requiring external sourcing. The CE framework also provides the bakery owner with guidance on ingredient sources and potential by-products for each ingredient.

5 THE CIRCULAR ECONOMY FRAMEWORK FOR SME BAKERIES

The functionality of the CE framework will be explained separately for each phase.

5.1.1 Phase 1

Figure 5 illustrates phase 1 of the CE framework, which begins by guiding the bakery owner in classifying the products produced in their bakery into the five primary bakery product categories. A bakery owner can choose between breads, cakes, muffins, pastries, cookies, biscuits, and speciality items.

1. Determine and classify the products to be produced in the bakery according to the bakery product categories to identify the most-used ingredients for the bakery.	Product					
	Bakery product categories	Breads	Cakes & Muffins	Pastries	Cookies & Biscuits	Speciality Items
	Definition of each category	Leavened baked goods made primarily from flour, water, and yeast or sourdough. Usually savory and consumed as a staple food.	Sweet, tender, and moist baked goods made with flour, sugar, fat, and eggs, often leavened with baking powder or soda. Meant for individual or group servings and often decorated or flavored.	Baked goods made with a higher fat content dough, often flaky or tender, and may be filled or topped. This includes laminated doughs (like croissants) and shortcrust bases (used in tarts and pies).	Small, flat, often sweet baked goods made from dough or batter, portioned before baking. Usually crisp or chewy, with a long shelf life.	Dessert-style items that don't fit cleanly into cakes, cookies, or pastries. These often include no bake items, layered desserts, or modern refrigerated treats.
Examples		White bread, whole wheat bread, rolls, baguettes, sourdough, focaccia.	Chocolate cake, cupcakes, loaf cakes, muffins, red velvet cake.	Croissants, Danishes, eclairs, pies, quiches, tarts.	Chocolate chip cookies, shortbread, rusks, biscuits, ginger snaps.	Brownies, peppermint crisp tart, fridge tarts, mouse cups, marshmallows.

Figure 5: Phase 1 of the framework

5.1.2 Phase 2

The next step (Figure 6) is for the bakery owner to determine the region the bakery will operate in and classify the region according to a specific biome, using, for example, the ArcGIS WWF Terrestrial Ecoregion interactive map (available at: WWF Terrestrial Ecoregions Of The World (Biomes)). Users can search for their city or region and identify the biome classification by clicking on the map, which assigns the location to one of 14 global biomes.

2. Determine the region the bakery falls in and classify the region according to a specific biome by using the ArcGIS WWF Terrestrial Ecoregion Interactive Map to identify the ingredients grown in the specified region.	Biome number	Biomes	Colour
	1	Tropical and subtropical moist broadleaf forests	Red
	2	Tropical and subtropical dry broadleaf forests	Orange
	3	Tropical and subtropical coniferous forests	Yellow
	4	Temperate broadleaf and mixed forests	Light Green
	5	Temperate Coniferous Forest	Green
	6	Boreal forests / Taiga	Blue
	7	Tropical and subtropical grasslands, savannas and shrublands	Dark Blue
	8	Temperate grasslands, savannas and shrublands	Dark Blue
	9	Flooded grasslands and savannas	Purple
	10	Montane grasslands and shrublands	Pink
	11	Tundra	Brown
	12	Mediterranean Forests, woodlands and scrubs	Grey
	13	Deserts and xeric shrublands	Light Green
	14	Mangroves	Red

Figure 6: Phase 2 Part 1 of the framework

Once the products produced in the bakery were categorised into the five primary bakery product categories and the region the bakery will operate in was classified according to a specific biome, the CE framework then guides the bakery owner to determine the most-used ingredients for each of the primary bakery product categories that can be produced in the specific biome (Figure 7). Furthermore, the CE framework then identifies potential sources and highlights potential by-products that may be incorporated into a CE strategy for each most-used ingredient. The bakery owners are advised to source the ingredients that cannot feasibly be produced on the farm (due to the biome that the farm is located in) from local suppliers. When looking at Figure 7. The input from the bakery owner will be the bakery product categories chosen in the first phase, as well as the biome determined in part 1 of the second phase. The output from the CE framework is the most-used ingredients that are marked with an X for each of the bakery product categories. The framework also provides the source of each of the most-used ingredients and the by-products produced for each of the most-used ingredients. The applicable biomes for each of the most-used ingredients are indicated by the coloured dots, which correspond to the colours used in Figure 6.

Part 3 of phase 2 of the CE framework will be addressed in future research, which will provide a comprehensive guide to the optimal uses of the possible by-products produced on the farm as well as the bakery, ensuring effective use within the SME bakery integrated with the farming operations.

Bakery product categories	Product								
	Breads	Cakes & Muffins	Pastries	Cookies & Biscuits	Speciality Items				
Most-used ingredients per category	X	X	X	X		Cake wheat flour	Soft wheat	● ● ● ●	Bran Germ
	X		X			Bread flour	Hard wheat	● ● ● ●	Bran Germ
	X	X	X	X		Sugar	Sugar cane	● ● ● ●	Bagasse Molasses Filtercake
	X	X	X	X		Salt	Outsourced (does not make sense)		
	X		X			Water	Environment (borehole/rainwater harvesting)		
	X					Instant dry yeast	Outsourced (does not make sense)		
		X	X			Milk	Cow	● ● ● ●	Urine Manure
	X		X	X		Butter	Cow	● ● ● ●	Buttermilk Urine Manure
		X	X	X		Eggs	Chicken	● ● ● ●	Egg shells Urine Manure Feathers Waste feed bedding and material
		X		X		Baking powder	Outsourced (does not make sense)		
		X				Canola oil	Canola	● ● ● ●	Hulls Meal
		X				Sunflower oil	Sunflower	● ● ● ●	Hulls Meal
		X	X	X		Vanilla extracts	Outsourced (does not make sense)		
		X	X	X		Flavourings	Depends on the flavourings used.		
						Ingredients	Received from	Applicable biomes	By-products

Figure 7: Phase 2, Part 2 of the framework

6 VERIFICATION

The conceptual model will be verified by checking compliance with the circular economy principles of the ReSOLVE framework that served as the design requirements. Table 3 shows a verification checklist that justifies why the model is verified.

Table 3: Verification checklist

Verification checklist		
Symbol	ReSOLVE principle	Justification
R	Regenerate	- Part 3 of Phase 2 of the CE framework will provide a comprehensive guide to the optimal uses of the possible by-products produced on the farm and in the bakery. - Rainwater harvesting and boreholes are also advised to support sustainable water usage.
S	Share	- This CE framework helps with knowledge sharing in the community. - Excess ingredients produced will be shared with the community.
O	Optimise	Phase 3 of the CE framework will be a tool designed to balance the bakery and farm processes to match demand and avoid overproduction.
L	Loop	- Bakery and farm by-products are worked back into the farm. - Farm products are used as the ingredients for the bakery.
V	Virtualise	This CE framework is a virtual technology that is designed to support decision-making in integrating bakery and farming processes to support environmental and economic sustainability.
E	Exchange	- Some of the by-products can be used to generate renewable energy instead of fossil fuels. - The use of local suppliers is advised rather than long-haul distribution chains.

Thus, the CE framework is verified as complying with all the design requirements.

7 CONCLUSION

The circular economy framework (CE framework) guides the design of a circular economy decision support model.

Without practical decision support systems, SME bakeries often lack the knowledge and guidelines needed to successfully implement an integrated system by aligning farm and bakery processes to support economic and environmental sustainability. By combining circular economy principles with both farming and bakery operations, the CE framework for SME bakeries provides a strategic framework towards mitigating these challenges. This study starts to address the critical challenges faced by SME bakeries, particularly the lack of technical, entrepreneurial, and operational skills that hinder their ability to operate efficiently, as well as the environmental sustainability challenges.

The CE framework offers a practical guideline towards aligning bakery operations with on-site farming activities. The model serves as a foundation for designing future circular economy decision support systems for SME bakeries integrated with farming processes.

The CE framework not only provides support towards economic growth and food security, but also contributes towards the broader goal of developing sustainable manufacturing practices in the bakery sector.

The contribution of this study lies in establishing a foundation for aligning bakery operations with smallholder farming activities through a circular economy lens. While the CE framework is only the first step, it demonstrates how integrated bakery-farm systems can close resource loops, reduce external dependencies, and strengthen food system resilience. Importantly, it

highlights a pathway for SME bakeries to move beyond survival strategies towards long-term sustainability and competitiveness.

8 FUTURE RESEARCH

The CE framework presented here should be viewed as a stepping stone toward a CE decision support system for SME bakeries. Future research should expand the integration phase, test the framework in real-world contexts, and validate its performance through scenario modelling.

Future work should focus on applying the CE framework to design a circular economy decision support system for SME bakeries (SME-CE-DSS). This system should allow users to input available space and generate balanced configurations of farm and bakery operations. For example, it should provide guidance on the appropriate ratios between livestock (e.g., cows and chickens), crop production, and bakery capacity to ensure that the overall system design is feasible and aligned with spatial and operational constraints.

The decision support systems should also enable SME bakery owners to make informed decisions regarding ingredient sourcing and regional agricultural feasibility. This could reduce the dependency on external inputs, lowering costs and promoting environmental sustainability.

9 REFERENCES

- [1] M. A. H. Chowdhury et al., "Enzyme applications in baking: From dough development to shelf-life extension," *International Journal of Biological Macromolecules*, vol. 282, pp. 4, 2024. [Online]. Available: <https://doi.org/10.1016/j.ijbiomac.2024.137020>.
- [2] WebstaurantStore. "Types of Bakeries: Pastry, Bread, Wedding & More." WebstaurantStore. Accessed Aug. 18, 2025. [Online.] Available: <https://www.webstaurantstore.com/article/307/types-of-bakeries.html#:~:text=The%20two%20main%20bakery%20business?msocid=277b1f60418c67aa08f310b640f466bf>
- [3] (2019). National Small Enterprise Act (Act No. 102 of 1996): Revised Schedule 1 of the National Definition of Small Enterprise in South Africa.
- [4] J. Erasmus and P. Cownie, "Investigation into the development of small and medium sized bakeries in South Africa," Human, Sciences Research Council & South African Chamber of Baking, Employment and Economic Policy Research Unit, Pretoria, South Africa, 2002.
- [5] C. D. Virginio et al., "Overcoming Challenges in the Quality Service and Production of a Bakery Business: A Literature Review," Available at SSRN 4031633, 2022.
- [6] R. Lozano, "Proposing a definition and a framework of organisational sustainability: A review of efforts and a survey of approaches to change," *Sustainability*, vol. 10, no. 4, pp. 1157, 2018.
- [7] B. Purvis, Y. Mao, and D. Robinson, "Three pillars of sustainability: in search of conceptual origins," *Sustainability Science*, vol. 14, pp. 681-695, 2019.
- [8] M. Lakovlieva, "Food waste in bakeries-quantities, causes and treatment," 2021.
- [9] J. Kirchherr, N.-H. N. Yang, F. Schulze-Spüntrup, M. J. Heerink, and K. Hartley, "Conceptualizing the circular economy (revisited): an analysis of 221 definitions," *Resources, conservation and recycling*, vol. 194, pp. 107001, 2023.
- [10] F. Fernqvist, "Farm to Fork Strategy-a consumer perspective," *SLU Future Food Reports*, no. 16, 2021.

- [11] B. Koul, M. Yakoob, and M. P. Shah, "Agricultural waste management strategies for environmental sustainability," *Environmental Research*, vol. 206, pp. 112285, 2022.
- [12] M. Nikolaou et al., "Valorisation of bakery waste via the bioethanol pathway," *Energy*, vol. 280, pp. 128185, 2023.
- [13] S. Grossi et al., "Feeding bakery former foodstuffs and wheat distiller's as partial replacement for corn and soybean enhances the environmental sustainability and circularity of beef cattle farming," *Sustainability*, vol. 14, no. 9, pp. 4908, 2022.
- [14] A. Malamakis et al., "Demonstration of an Integrated Methodology for the Sustainable Valorisation of Bakery Former Food Products as a Pig Feed Ingredient: A Circular Bioeconomy Paradigm," *Sustainability*, vol. 15, no. 19, pp. 14385, 2023.
- [15] V. Imeneo, A. Piscopo, S. Santacaterina, A. De Bruno, and M. Poiana, "Sustainable Recovery of Antioxidant Compounds from Rossa Di Tropea Onion Waste and Application as Ingredient for White Bread Production," *Sustainability*, vol. 16, no. 1, pp. 149, 2023.
- [16] I. Fernandez-Pan, F. C. Ibañez, P. Virseda, I. Arozarena, and M. J. Beriain, "Stabilization and valorization of tomato by-product: A case study for the bakery industry," *Journal of Food Science*, vol. 88, no. 11, pp. 4483-4494, 2023.
- [17] P. Manickam and G. Duraisamy, "3Rs and circular economy," in *Circular economy in textiles and apparel*: Elsevier, pp. 77-93, 2019.
- [18] A. Payne and E. M. Kwofie, "Unleashing circular economy potential in agriculture: Integrating social impact assessment with the ReSOLVE framework as a tool for sustainable development," *Sustainable Development*, vol. 32, no. 5, pp. 5074-5089, 2024.
- [19] S. P. Cauvain, *Baking problems solved*. Woodhead Publishing, 2017.
- [20] D. M. Olson et al., "Terrestrial Ecoregions of the World: A New Map of Life on Earth: A new global map of terrestrial ecoregions provides an innovative tool for conserving biodiversity," *BioScience*, vol. 51, no. 11, pp. 933-938, 2001.
- [21] P. W. Buys and M. Oberholzer, *Business Research An Illustrative Guide to Practical Methodological Applications in Selected Case Studies*. palgrave macmillan, 2023.
- [22] M. Saunders, P. Lewis, and A. Thornhill, "Research methods for business students," Essex: Prentice Hall: Financial Times, 2003.