## Frugal Meets Circular: A Transformative Approach towards Sustainability

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# Frugal Meets Circular: A Transformative Approach towards Sustainability

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## Keywords

Frugal Innovation, Circular Economy, Circularity, Frugality, Sustainability, Sustainable Development Goals

## Abstract

Sustainability is a holistic notion that encompasses environmental, social, and economic factors as its core components. Approaches attempting to balance the three pillars of sustainability have faced criticism due to the challenge of comparing values such as biodiversity, landscape beauty, costs, profitability, equity, health, and cultural values, which are not clearly commensurable. The concepts of Frugal Innovation and Circular Economy have made significant contributions to advance sustainability and SDGs. Frugal Innovation refers to developing affordable solutions with limited resources while maintaining quality. Circular economy refers to closing the material loop while minimizing waste and maximizing resource use. Scholars have discussed the role of Frugal Innovation and Circular Economy independently in achieving sustainability, however studies integrating these two concepts together are limited. This study explores the interaction between Frugal Innovation, Circular Economy and Sustainability. To advance this knowledge, a systematic literature review supported by PRISMA review methodology has been conducted from the year 2014 until 2024. Our results indicate the synergistic effect of frugal innovation and circular economy in advancing sustainability. Both concepts support each other by increasing efficiency, producing sustainable affordable solutions and scalability. From a policy level, there is a need to develop a conceptual framework integrated with the United Nation (UN) SDGs that are mostly targeted by Circular Economy and Frugal Innovation. Overall, it is particularly important that all stakeholders including government, industry and academia collaborate to promote integrated Circular Economy and Frugal Innovation strategies through aligned policies and joint initiatives.

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## 1. Introduction

"Making peace with nature is the defining task of the 21st century."[2] This statement by António Guterres, 9th Secretary-General of the United Nations, was a famous and successful attempt to foster worldwide ambitions on climate change for the coming years. However, in 2024, the world is quite different from what most people would have expected based on the discussions in the year 2020. It is not only the COVID-19 pandemic which led to different technological and societal challenges [1]. It is especially and foremost the worldwide crisis related to climate change which partly dramatically forces individuals, but also governments and companies to change their behaviors. Sustainability is not at the core anymore, it is much more about international trade issues, several wars in Ukraine or Israel, and related refugee movements. The world economic situation is again at the core of governmental decisions. As a result, saving programs are being introduced at a governmental, but also at a corporate level. Ultimately, in combination with high inflation in recent years, this has also led to households having less consumption.[3]

These developments support a phenomenon called frugality, which gains popularity worldwide. The Economist (2010) defined frugal innovation as "Instead of adding bells and whistles to the product, stripping the product down to its bare essentials [2]." The core of frugal innovation lies in delivering essential functionality through simplicity and acceptable quality with the focus of doing more with less. An innovation is considered frugal if it meets the three criteria as identified by [3], [4] i.e. it should have low cost, it should focus on core functionalities and should have an optimized performance level.

Climate change, economic uncertainty and global inequality are the challenges facing the world today. These challenges along with the motivation to achieve sustainability have intensified the need for resource efficient and affordable solutions [3], [5]. In so-called developed countries, people voluntarily expose themselves to resource constraints, even though they could afford everything. So, people could for instance afford to live in a flat, but they prefer living in tiny houses or vacation in tents. But also buying only used clothes or only using public transport, are some examples of frugality which can be observed in European countries like France or Germany [6], [7]. In so-called emerging and developing economies, such as India or China, people suffering from resource constraints are forced to develop products facing these constraints [8]. When done with technological approaches at an acceptable quality level, this can be referred to as frugal innovations (FIs) [9], [10]. These innovations have become a worldwide phenomenon since FIs emergence [11]. Since global wealth and consumption increase, the question of how much higher resource consumption could be covered is raised. For instance, natural resource consumption is globally forecasted to rise by 60% by 2060.[4]

Here, the concept of circular economy (CE) comes into play: the extension of product lifecycles in each detail. Established many years ago in the 1970s and 1980s, it gets new attention through its linkage to climate change mitigation [12]. Hence, with the surge of the climate protection movement, this concept again receives increasing attention from research and practice. CE is apparently strongly related to sustainability too, which is a long-established concept as well. A comprehensive definition is given by [13] who highlight five dimensions of sustainability: "(1) after a defined period of time, (2) the program, clinical intervention, and/or implementation strategies continue to be delivered and/or (3) individual behavior change (i.e., clinician, patient) is maintained; (4) the program and individual behavior change may evolve or adapt while (5) continuing to produce benefits for individuals/systems."

Frugal innovation and circular economy have the potential to foster sustainability in times of constraints. Such constraints could come from resource limitations, or from a lower focus on sustainable behaviors based on the current economic situation, as outlined earlier. Frugal innovation fosters sustainability by generating greater value with fewer resources, producing affordable solutions and by incorporating less affluent consumers into the market [14], [3],[15]. Circular economy on the other hand directly supports sustainability by minimizing waste generation and closing the material loops through reuse, reduce, and recycling techniques [16], [17]. Also, both frugal innovation and circular economy refer to the individual

[2] https://unfccc.int/news/un-secretary-general-making-peace-with-nature-is-the-defining-task-of-the-21st-century
[3] https://www.ecb.europa.eu/press/economic-bulletin/focus/2024/html/ecb.ebbox202402_03~289573ea78.en.html
[4] https://www.weforum.org/agenda/2024/03/sustainable-resource-consumption-urgent-un/

contribution to sustainable behaviors, which have in sum the strongest cumulative impact of all possible sustainability actions [18].

To advance sustainability and to contribute positively towards sustainable development goals (SDGs), frugal innovation and circular economy have gained significant attention [19], [20]. Most existing studies focused on the relationship between frugal innovation and sustainability, particularly sustainable development [21], [22], [23], [24], [25]. Similarly, scholars have explored a contribution of circular economy to sustainability particularly to the environmental aspect of sustainability [26], [27], [28]. While scholars have explored the individual impact of frugal innovation and circular economy on sustainability, a clear gap remains in understanding the cumulative effect of these two concepts on sustainability. The aim of this research is to identify the cumulative effect of frugal innovation and circular economy on sustainability. In a nutshell, this study aims to answer these two research questions- What are the connections and interlinkages between FI and CE? And how does this relationship impact on sustainability? To best of our knowledge, there is no earlier study focusing on this relationship.

Drawing from the findings of this study, we put forth our suggestions and recommendations for future research directions, but also for managerial and policy practice. This is the first systematic literature analysis connecting these emerging phenomena and presenting a conceptualization of their connectivity. Our results indicate that considering frugal innovation and circular economy together will generate synergistic effects that enhance overall sustainability outcomes.

The subsequent sections of this article are organized as follows: First, we describe our systematic literature approach. Then we show our general results, introduce further analysis insights, which then lead to our final discussion and conclusion. This article closes with limitations and future research directions.

## 2. Method of Analysis

### 2.1 Steps involved in systematic literature review

To evaluate how FI and CE impacts sustainability, the contents of relevant studies were analyzed qualitatively based on a systematic literature review. A systematic review of the literature is an effective and transparent method of collecting, combining, and evaluating the outcomes of studies on a specific issue. Following the methodology [29], three phases were implemented:
1. Mapping the field by means of scoping review
2. Comprehensive search of the relevant literature
3. Quality assessment of the studies
A qualitative content analysis was used for the remaining three phases (4. Extraction of data, 5. Synthesis of data, and 6. Conclusion as a write up) as a more methodical and structured technique. Qualitative content analysis relies heavily on textual analysis of material collected. A general procedure guides this approach as well as the application of a particular system. A theory-driven approach is used to organize the material into categories and subcategories. Based on the data collected, qualitative text analysis was conducted using MAXQDA, a qualitative data analysis software [30].

### 2.2 Mapping the field by means of scoping review

Four keywords have been used in the study to search for relevant literature and for collection of data. To ensure comprehensive coverage of the literature at the intersection of frugal innovation, the circular economy, and sustainability, a tiered keyword strategy has been applied. Each set of keyword builds on the foundational terms “frugal innovation” and “circular economy” by progressively incorporating “indicators” and “sustainability”. This method provided greater depth in identifying relevant publications by using four distinct search pathways that all lead to the same destination. We also tested for keywords “circular” or “circularity” in addition to the below mentioned keywords “Frugal Innovation And Circular Economy”, “Frugal Innovation” And “Circular Economy” And “Indicators”, “Frugal Innovation” And “Circular Economy”, “Frugal Innovation” And “Circular Economy” And “Indicators” And “Sustainability.” However, these additional terms did not yield any new relevant results. All relevant articles referred explicitly to “Circular Economy” rather than the standalone terms “circular” or “circularity”. Therefore, we excluded these broader terms from our final keyword set.

The following search strings have been used in the study:

- Keyword 1: (“Frugal Innovation and Circular Economy”)
- Key word 2: (“Frugal Innovation” And “Circular Economy” And “Indicators”)
- Keyword 3: (“Frugal Innovation” And “Circular Economy”)
- Keyword 4: (“Frugal Innovation” And “Circular Economy” And “Indicators” And “Sustainability”)

### 2.3 Inclusion criteria, exclusion criteria and screening process

The following inclusion and exclusion criteria have been applied while searching for the relevant literature.

**Inclusion criteria:**

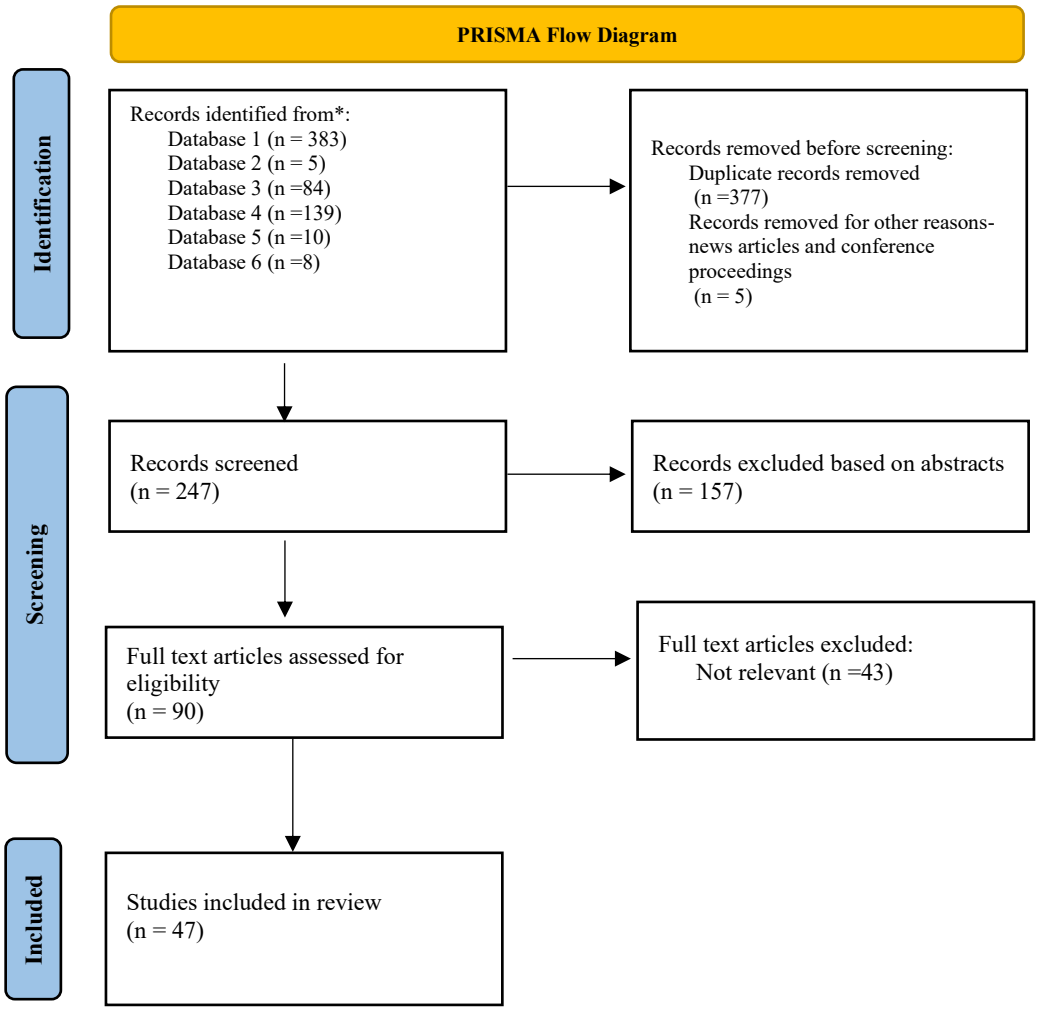
- Journal articles published between the timeline 2014 until 2024
- Articles written in English language
- Articles focused on the relationship of frugal innovation, circular economy, and sustainability
- Both conceptual and empirical studies are considered

**Exclusion criteria:**

- News based articles, blogs, online articles, magazines articles, conference proceedings, editorials etc. are not included
- Articles not addressing the core relationship between frugal innovation, circular economy and sustainability

**Screening process – PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) Review Methodology**

To gather extensive data, we considered six databases (EBSCOhost, JSTOR, ProQuest, ScienceDirect, Scopus, and WOS (Web of Science)) for a comprehensive search on 30 July 2024. Searches on Google Scholar were performed manually if the texts could not be downloaded or accessed from the databases. The analysis focused on articles in English language only because English is considered as a global scientific language, and it gives us the opportunity to include several widely recognized and cited research articles. We have used the PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) Review Methodology to get the desired results. Records identified from each database are also presented in table 1. Apparently, this brings some limitations and future research potentials, which are discussed later in the corresponding section.




*Records identified from each database are shown in the table (1) below

| Sr. | Databases | Keyword 1* | Keyword 2** | Keyword 3*** | Keyword 4*** | Total |
|---|---|---|---|---|---|---|
| 1 | Proquest | 1 | 108 | 170 | 104 | 383 |
| 2 | JSTOR | 0 | 1 | 3 | 1 | 5 |
| 3 | EBSCO HOST | 21 | 21 | 21 | 21 | 84 |
| 4 | Science Direct | 1 | 35 | 68 | 35 | 139 |
| 5 | Scopus | 1 | 1 | 8 | 0 | 10 |
| 6 | Web of science | 0 | 1 | 7 | 0 | 8 |
| | **Total** | 24 | 167 | 277 | 161 | 629 |

Table 1- Records identified from each database in the PRISMA flow diagram
Keyword 1*- "Frugal Innovation and Circular Economy"
Keyword 2**- "Frugal Innovation" And "Circular Economy" And "Indicators"
Keyword 3***- "Frugal Innovation" And "Circular Economy"
Keyword 4****- "Frugal Innovation" And "Circular Economy" And "Indicators" And "Sustainability"

## 2.4 Quality assessment

To assess the quality of the text for the analysis, we consider the relevance of the text related to frugal innovation, circular economy and sustainability. Some of the articles were based on "Circular Policies" and "Life-cycle Assessment", but no link was found to exist with sustainability and therefore they were not considered [31],[32],[33]. To be included in the study, the article must demonstrate a clear link between sustainability and either frugal innovation, circular economy or both with frugal innovation and circular economy. Most of the articles addresses both "Frugal Innovation" and "Circular Economy" [34], [35], while some focused either on "Frugal Innovation" or "Circular Economy" [36], [21],[37]. Nevertheless, all these articles were included in the study because of their relevance to sustainability.

We assessed quality based on conceptual rigor. To be included in the study, articles should demonstrate explicitly the linkages of sustainability with either frugal innovation, circular economy or with both, and the terms (frugal innovation and circular economy) are clearly defined. For instance, articles that considered the determinants related to the acceptance of FI in relation to consumers were excluded from the study [38]. In addition, studies related to planned behavior in household waste and multi-dimensional perspective of green financial innovation were also excluded [39],[40]. Furthermore, terms like "Jugaad Innovation", "Reverse Innovation", and "Sustainable Innovation" were not included in the study. In total, 629 articles were collected from six different databases. After removing duplicates across 4 keywords and six databases, 252 unique articles remained for further analysis. Because only academic publications were included in the study, 5 news articles and conference proceedings were removed from the data set, resulting in 247 articles for further screening. These were then screened by title and abstract, after which 90 articles were selected for full-text review (also shown in the PRISMA flow diagram) resulting into 47 studies which were retained for further analysis. The results are shown below (Table 2).

| Databases | Keyword 1* | Keyword 2* | Keyword 3* | Keyword 4* | Total | Final numbers after removing Duplicates | Final number after removing duplicates among the databases | After scanning abstracts | Final studies included after full scan of the articles |
|---|---|---|---|---|---|---|---|---|---|
| **Proquest** | 1 | 108 | 170 | 104 | 383 | 167 | **252** | **90** | **47** |
| **JSTOR** | 0 | 1 | 3 | 1 | 5 | 3 | | | |
| **EBSCO HOST** | 21 | 21 | 21 | 21 | 84 | 21 | | | |
| **Science Direct** | 1 | 35 | 68 | 35 | 139 | 69 | | | |
| **Scopus** | 1 | 1 | 8 | 0 | 10 | 8 | | | |
| **Web of Science** | 0 | 1 | 7 | 0 | 8 | 7 | | | |
| **Total** | 24 | 167 | 277 | 161 | 629 | **275** | | | |

Table 2: Detailed results from the database

Ultimately, 47 articles were considered, as shown below in the Tables (3). We have included the title of the text, author name, journal, publication year and type of the paper (conceptual or empirical as well as the total number of cases in the empirical paper) and the field it is related to in the table below.

| Sr. | Title | Ref | Journal | Year | Type | Field |
|---|---|---|---|---|---|---|
| 1 | Circular economy and frugal innovation: a conceptual nexus | [41] | Environmental Science and Pollution Research | 2022 | Conceptual and empirical | Frugal and Circular |
| 2 | Sustainable frugal innovation - The connection between frugal innovation and sustainability | [21] | Journal of Cleaner Production | 2019 | Conceptual | Frugal and Sustainability |
| 3 | Frugal supply chains: a managerial and societal perspective | [42] | Society and Business Review | 2019 | Conceptual | Frugal |
| 4 | Opportunities of frugality in the post-corona era | [43] | Int. J. Technology Management | 2020 | Conceptual | Frugal |
| 5 | Frugal innovation approaches to sustainable domestic energy: Two cases of solar water heating from Brazil | [22] | International Journal of Technological Learning, Innovation and Development | 2018 | Conceptual and empirical | Frugal and Sustainability |
| 6 | Key capabilities for frugal innovation in developed economies: insights into the current transition towards sustainability | [24] | Sustainability Science | 2022 | Empirical | Frugal and Sustainability |
| 7 | Value capture and value creation: The role of information technology in business models for frugal innovations in Africa | [44] | Technological Forecasting & Social Change | 2018 | Conceptual and empirical | Frugal |
| 8 | The prospects of advanced frugal innovations in different economies | [45] | Technology in Society | 2022 | Conceptual and empirical | Frugal |
| 9 | The Sound of a Circular City: Towards a Circularity-Driven Quietness | [46] | International Journal of Environmental research and public health | 2022 | Empirical | Circular |
| 10 | Circular law as a legal basis for a circular economy | [47] | Earth and Environmental Science | 2021 | Conceptual | Circular |
| 11 | Defining frugal innovation: a critical review | [48] | Review | 2021 | Conceptual | Frugal |
| 12 | Pursuing Frugal Innovation for Sustainability at the Grassroots Level | [49] | Management and Organization Review | 2021 | Conceptual and empirical | Frugal and Sustainability |
| 13 | Towards Circular Business Models: A systematic literature review on classification frameworks and archetypes | [50] | Journal of Cleaner Production | 2019 | Conceptual | Circular |
| 14 | 3D-printed activated charcoal inlet filters for oxygen concentrators: A circular economy approach | [51] | Development Engineering | 2022 | Empirical | Circular |
| 15 | Circular economy – From review of theories and practices to development of implementation tools | [36] | Resources, Conservation & Recycling | 2018 | Conceptual | Circular |
| 16 | A conceptual merging of circular economy, degrowth and conviviality design approaches applied to renewable energy technology | [35] | Journal of Cleaner Production | 2021 | Conceptual | Circular |
| 17 | Australian SME's experience in transitioning to circular economy | [52] | Journal of Business Research | 2022 | Empirical | Circular |
| 18 | Creative upcycling: Reconnecting people, materials and place through making | [26] | Journal of Cleaner Production | 2018 | Conceptual and empirical | Circular |
| 19 | Design, management and control of demanufacturing and remanufacturing systems | [53] | CIRP Annals - Manufacturing Technology | 2017 | Conceptual | Circular |
| 20 | Do we need a 'circular society'? Competing narratives of the circular economy in the French food sector | [54] | Ecological Economics | 2021 | Conceptual and empirical | Circular |
| 21 | Enablers and barriers to implementation of circular economy in solid waste valorization: The case of urban markets in Anambra, Southeast Nigeria | [27] | Environmental and Sustainability Indicators | 2021 | Conceptual and empirical | Circular |
| 22 | Frugal approach to innovation: State of the art and future perspectives | [55] | Journal of Cleaner Production | 2018 | Conceptual and empirical | Frugal |

| | | | | | | |
|---|---|---|---|---|---|---|
| **23** | Frugal innovations: A multidisciplinary review & agenda for future research | [56] | Journal of Business Research | 2022 | Conceptual | Frugal |
| **24** | Necessity-driven circular economy in low-income contexts: How informal sector practices retain value for circularity | [37] | Global Environmental Change | 2022 | Conceptual and empirical | Circular |
| **25** | Practising circles: Studying institutional change and circular economy practices | [57] | Journal of Cleaner Production | 2019 | Conceptual | Circular |
| **26** | Sustainable development in the construction industry: The role of frugal innovation | [23] | Journal of Cleaner Production | 2022 | Conceptual and empirical | Frugal and Sustainability |
| **27** | Sustainable packaging for supply chain management in the circular economy: A review | [58] | Journal of Cleaner Production | 2019 | Conceptual | Circular |
| **28** | Value Creation through Frugal Innovation, Innovation Capability and Knowledge Sharing in a Circular Economy | [59] | Sustainability | 2022 | Empirical | Frugal and Circular |
| **29** | Modeling circular economy innovation and performance indicators in European Union countries | [60] | Environmental Science and Pollution Research | 2023 | Empirical | Circular |
| **30** | The Digital Transformation of Business Model Innovation: A Structured Literature Review | [61] | Frontiers in Psychology | 2021 | Conceptual | Frugal |
| **31** | Frugal innovation in wound care: a critical discussion of what we can learn from low-resource settings. | [62] | British Journal of Nursing | 2022 | Empirical | Frugal |
| **32** | Frugal innovation in wound care: the five Rs | [63] | British Journal of Healthcare Management | 2023 | Empirical | Frugal |
| **33** | How is the circular economy embracing social inclusion? | [64] | Journal of Cleaner Production | 2023 | Empirical and conceptual | Circular |
| **34** | Combining the characteristics of sustainability, frugal innovations and washing machines in the industrial nations – A literature-based analysis of the common features for future sustainable developments | [65] | Journal of Economic Development, Environment and People | 2020 | Empirical | Frugal |
| **35** | Doing more with less - How frugal innovations can contribute to improving healthcare systems. | [66] | Social Science & Medicine | 2022 | Empirical | Frugal |
| **36** | Frugal innovation: doing more with less | [67] | Philosophical Transactions of the Royal Society A | 2021 | Conceptual and Empirical | Frugal |
| **37** | A 3D-printed condom intrauterine balloon tamponade: Design, prototyping, and technical validation | [68] | PLoS ONE | 2024 | Empirical | Frugal and Circular |
| **38** | Frugal innovation development for sustainability: The case of extractivism of the “Butia catarinensis” in Brazil | [69] | Journal of Cleaner Production | 2023 | Empirical | Frugal |
| **39** | Crafting Sustainable Development Solutions: Frugal Innovations of Grassroots Entrepreneurs | [70] | Sustainability | 2016 | Empirical | Frugal |
| **40** | Research on home appliance circular design strategy in response to carbon border adjustment mechanism | [28] | Energy Strategy Reviews | 2024 | Empirical | Circular |
| **41** | Backcasting frugally innovative smart sustainable future cities | [71] | Journal of Cleaner Production | 2023 | Empirical | Frugal |
| **42** | Serving society at large. Operationalization and evidence of (advanced) frugal innovation in industrialized economies | [72] | Technological Forecasting & Social Change | 2024 | Empirical | Frugal |
| **43** | Roles of innovation in achieving the Sustainable Development Goals: A bibliometric analysis | [73] | Journal of Innovation and Knowledge | 2024 | Conceptual | Frugal and Circular |
| **44** | Frugal innovation for sustainable rural development | [25] | Technological Forecasting & Social Change | 2023 | Empirical | Frugal |
| **45** | The Emergence of Personalized Health Technology. | [74] | Journal of Medical Internet Research | 2016 | Conceptual | Frugal |
| **46** | Implications of Frugal Innovations on Sustainable Development: Evaluating Water and Energy Innovations | [75] | Sustainability | 2016 | Empirical | Frugal |
| **47** | Environmental sustainability in healthcare systems: role of frugal innovation | [76] | The BMJ | 2023 | Empirical | Frugal |

Table 3: Papers related to Frugal innovation, Circular economy, and Sustainability

## 3. General results of the analysis

There are various approaches available to assess the sustainability impact of FI and CE. The approach that we used to assess the sustainability impact was similar to that used in another study [21]. We used the TBL approach to identify and determine the impact of frugal innovation and circular economy on the granular level of sustainability i.e. economic, ecological and social. In addition, to determine the broader impact of frugal innovation and circular economy we included SDG-based approach to see which goals are particularly targeted by frugal innovation and circular economy. The main motivation to use these two approaches together is to provide a comprehensive and holistic view of these two concepts in terms of sustainability. Besides assessing social, economic, and environmental dimensions, this study also considers their extended dimensions.

To begin with, we present the generalized results based on our analysis in the Table 4 below. In table (4), we have included the assessment from three dimensions of sustainability, and we included the SDG targeted by the study. If the study does not mention sustainable development goals directly or indirectly, the corresponding section in the table left blank.

| Ref | Assessment of the Sustainability Impact | Targeted SDGs |
|---|---|---|
| [41] | social equity, economic prosperity, and environmental quality, Frugal Innovation can be served as an enabling tool to promote circular economy, conceptual with three cases, fit into SDGs | |
| [21] | Frugal innovation is inherently socially and economically sustainable, promote Sustainable Development Goals, new term "ecological sustainable frugal innovation" for frugal innovation with a positive connection to ecological sustainability. | |
| [42] | Competitive advantage for companies and an enhancement of their commitment to society, the circular economy represents many opportunities for new forms of growth in the context of rare resources, promote sustainable development. | |
| [43] | Frugality is likely to emerge as a mega-trend that may shape a frugal 'affordable green excellence' (AGE) as the dominant innovation paradigm. The overlap of frugal innovations with the principles of circular economy could act as a driver for the latter, and environmental sustainability can only be achieved when it is married to the concept of frugality, to reach sustainable development goals including in the economically advanced nations | |
| [22] | frugal approaches represent viable alternatives in achieving circular products and that these approaches can contribute to a socially inclusive form of environmentally friendly domestic energy use, social sustainability | |
| [24] | Promote Sustainable development goals, social, economic and environment sustainability | |
| [44] | Social, Economic and Ecological sustainability dimensions | |
| [72] | Economic and societal necessity to establish frugal design principles at the regime level, Social, economic and ecological, indirect link with SDGs | |
| [46] | Ecological Sustainability | 13 |
| [47] | Economic, Ecological, Promote SDGS | 12 |
| [48] | FI can create new markets and contribute towards a more sustainable and inclusive world by supporting a more circular economy, socio-economic impact, ecological sustainability | |
| [49] | the impact of frugal innovations developed at the grassroots level is stronger in the social and economic aspects than in the environmental aspect, drive SDGs | |
| [50] | Economic and Ecological | 8,13 |
| [51] | Social, Ecological, Promote SDGs | 3,9,10,12,13,15 |
| [36] | Economic, ecological, Promote SDGs | 8, 12 |
| [35] | social dimensions, SDGs | 3, 8 |
| [52] | Social, Economic and Ecological sustainability, Promote SDGs | 8, 13 |
| [26] | Social, Economic and Ecological sustainability, Promote SDGs | 3, 8,13 |
| [53] | Social, Economic, Ecological, Fit to SDGs | 7,13,8,12 |
| [54] | Economic and Ecological | 8,13,10 |
| [27] | Economic, Social and Ecological and promote Sustainable development goals | 3,8,13,12 |
| [55] | sustainable, socio-economic change and can contribute to increasing healthy living conditions for the population, promote SDGs | |
| [56] | Ecological and Economic sustainability | |
| [37] | Economic, Promote SDGs | 8,10,12,13 |

| | | |
|---|---|---|
| [57] | Economic, social and Ecological and indirectly Sustainable development goals | 8,13 |
| [23] | Economic, Social and Ecological sustainability, Promote sustainable development | |
| [58] | Economic, social, ecological, Promote Sustainable development goals | 3,8,12,13 |
| [59] | Frugal innovation can help firms redesign their operations and reduce costs significantly. Frugal innovation enhances innovative capabilities of SMEs in circular economy | |
| [60] | Ecological | |
| [61] | Frugal innovation supports in reducing costs around the entire value chain | |
| [62] | Frugal innovation provides affordable digital solutions that improve patient outcomes and economic efficiency. | |
| [63] | Frugal innovation provides affordable low-cost solution in healthcare | |
| [64] | Research in the field of circular economy primarily concentrates on reuse, reduce, and recycle with little regard for social inclusion. | |
| [65] | Economic, social and ecological | 3,4,7,9,10,12,13,15 |
| [66] | Economic and social | |
| [67] | Economic and social | |
| [68] | Frugal innovation supports healthcare in producing low-cost economic innovation. Circular economy is ecologically feasible for medical devices through its 3R approach (reuse, reduce and recycle). | 3 |
| [69] | Economic, social and ecological | 1,8,9,4 |
| [70] | Economic and social | 1,3,8,9,12 |
| [28] | Ecological and economic efficiency | |
| [71] | Social, ecological and economic | |
| [72] | Social, economic and ecological | 11 |
| [73] | Frugal innovation supports economic sustainability through cost-effective solutions. Circular economy contributes towards sustainable development goals. | 6,8,12,15 |
| [25] | Social, economic and ecological | 1,5,8,9,11,12 |
| [74] | Social and Economic | |
| [75] | Economic and social | |
| [76] | Social and economic | |

Table 4: Generalized results based on the analysis

### 3.1 Sustainability Dimensions

The results for the three dimensions of sustainability were calculated based on all empirical case studies. Out of the total of forty-seven, in fourteen studies empirical findings were presented in relation to the three dimensions of sustainability, i.e., economic, social, and ecological. Some of the studies consist of more than one case such as three cases [1], so based on each case study the three dimensions were scored (as shown in table 5). One or two dimensions of sustainability were analyzed in five of these texts [22], [46], [51], [54], [70]. All the other nine texts analysed all the three dimensions of sustainability. After that each dimension's score was added to determine the results. With a score of 61 points, the economic and ecological dimension ranked highest, followed by the social dimension with 47 points. To calculate the percentage, we added the scores from each dimension and divided them by the total score. Based on the results it appears that economic and ecological accounts for 36.09% and social for 27.81% in the cases studied as shown in Table (5) below.

| Ref: number of cases | Economic | Social | Ecological |
|---|---|---|---|
| [41]: 3 cases | 3 | 3 | 3 |
| [22]: 2 cases | - | 2 | 2 |
| [44]: 1 case | 1 | 1 | 1 |
| [45]: 1 case | 1 | 1 | 1 |
| [46]: 1 case | - | - | 1 |
| [49]: 3 cases | 3 | 3 | 3 |
| [51]: 1 case | - | 1 | 1 |
| [52]: 16 cases | 16 | 16 | 16 |
| [26]: 1 case | 1 | 1 | 1 |
| [54]: 17 cases | 17 | - | 17 |
| [27]: 1 case | 1 | 1 | 1 |
| [23]: 1 case | 1 | 1 | 1 |
| [70]: 4 cases | 4 | 4 | - |
| [25]: 13 cases | 13 | 13 | 13 |
| Total | 61 | 47 | 61 |
| Percentages | 36.09% | 27.81% | 36.09% |

Table 5: Analysis of the sustainable cases

### 3.2 Economic

The economic aspect of sustainability has been considered in numerous studies. After careful consideration of the studies and to make things easier to understand, we divide the economic dimensions in different sub-categories. Based on the recurrent themes and patterns present in the texts, these categories are inductively derived from the The categories themselves are self-explanatory; therefore, we only included the number of codes below for the whole data.

- Value to low-income consumers (15 codes)
- Local opportunities (22 codes)
- Low cost of raw materials (19 codes)
- Green supply chains / redesigning the supply chains (6 codes)
- Competitive business models (8 codes)
- Business growth or revenues (17 codes)
- Increases GDP and employment opportunities (17 codes)

### 3.3 Social

The social aspect of sustainability is also considered in numerous studies. After careful consideration, we categorized the data into six dimensions. Since the categories themselves are self-explanatory, the number of codes below is all we included for the whole set of data.

- Guarantees equivalent access to products and services for wealthier people & poor people (15 codes)
- Provides new educational opportunities (4 codes)
- Philanthropic work for society (3 codes)
- Social inclusion and wellbeing (25 codes)
- Improves brand reputation (2 codes)
- Relationship with customers (5 codes)

### 3.4 Environmental

From the forty-seven analyzed texts, numerous consider the environmental aspect of sustainability. We put all available data into seven categories. Due to the fact that the categories themselves are self-explanatory, the number of codes below is all we included for the whole set of data.

- Waste management (25 codes)
- Less emissions (17 codes)
- Environment friendly production and consumption (20 codes)
- Low dependence on virgin materials (14 codes)
- Renewable energy (9 codes)

original texts. We have created seven categories in total, i.e., value to low-income consumers, local opportunities, low cost of raw materials, green supply chains / redesigning the supply chains, competitive business models, business growth or revenues, and increase GDP and employment opportunities which refers to the indicators or impacts of economic activity used in the studies.

- Noise mitigation and healthy environment (8 codes)
- Reduces the use of physical resources (7 codes)

### 3.5 Integrated dimensions

The integrated dimensions of sustainability were considered in almost all studies. Integrated dimensions refer to a study that incorporates two or three dimensions simultaneously. In addition, we also added an extended dimension to the three original dimensions as it appeared in the analyzed texts. Following are five categories that we used to classify the integrated dimensions:

- Social and Economic (9 codes)
- Social and Environmental (10 codes)
- Economic and Environmental (13 codes)
- Social, Economic and Environmental (10 codes)
- Socio-political and economic (1code)

### 3.6 Sustainable development goals

We considered 47 articles to identify their direct and indirect contribution towards the Sustainable Development Goals. From these 47 articles, we adjusted the values with reference to the number of cases and their contribution towards the specific goal. For example, if an article consisted of 3 cases and contributes to 4 SDGs, then we assigned the value of 3 to all 4 SDGs separately [41]. We also separated the SDG contributions of the same article when it addressed both frugal innovation and circular economy. For example, the study [41] covers both concepts, but its contributions to the SDGs differ between the concept of frugal innovation and circular economy. Therefore, the study is listed twice—once under each concept. For the conceptual texts, a value of 1 was assigned to the relevant SDG being directly or indirectly impacted [21]. To analyze the contribution of the 47 texts towards SDGs, a total of 68cases were considered from the 15 empirical studies along with the remaining 19 conceptual texts.

As demonstrated from the Table (6) below, it can be seen that the most contribution of the analyzed 47 empirical and conceptual texts was towards SDG no. 8 “Decent work and economic growth" with a value of 73 (36%), followed by SDG 13 (Climate action) with a value of 55 (19%).Furthermore, the contribution towards SDG no. 12 “Responsible consumption and production” was found with a value of 31 (11%), SDG no. 10 (Reduced inequalities) with a value of 27 (9.4%) and SDG no.1 “No poverty” with a value of 26 (9.1%) and SDG no. 9 “Industry, innovation and infrastructure” with value of 20 (7%). SDG no. 11 “Sustainable cities and communities”, SDG no.3 “Good health and well-being” and SDG no. 5 “Gender equality” were found to have a value of around 15, 14 and 13 (around 5%). SDG no. 7 “Affordable and clean energy” with a value of 5(2%). SDG no. 15 “Life on land with a value of 3 (1%), and minimal contribution by SDG no. 6 “Clean water and sanitation” and SDG no.4 “Quality education”, SDG no. 2 “Zero hunger” and SDG no. 15 “Life on land” were found to have a value of 1 (0.6%). There is no contribution towards SDG no. 14 “Life below water”, SDG no. 16 “Peace, justice and strong institutions”, and SDG no. 17 “Partnerships for the goals”

| SDGs<br>Ref-number of cases | Concept | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| [41]- 3 cases | Frugal | 3 | | | | | | | 3 | | 3 | | | | | | | |
| [41]- 3 cases | Circular | | | | | | | | | | | | | 3 | | | | |
| [21] | Frugal | 1 | | | | | | | 1 | | | | | 1 | | | | |
| [42] | Frugal | | | | | | | | | | | | 1 | | | | | |
| [43] | Frugal | | | | | | | | | | | | | 1 | | | | |
| [22]- 2 cases | Frugal | | | | | | | 2 | 2 | | | | | | | | | |
| [24] | Frugal | 1 | | | | | | | 1 | | | | | 1 | | | | |
| [44]- 1 case | Frugal | | 1 | | | | | | 1 | | | | | 1 | | | | |
| [45] - 1 case | Frugal | 1 | | | | | | | | | | | 1 | 1 | | | | |
| [46]- 1 case | Circular | | | | | | | | | | | | | 1 | | | | |
| [47] | Circular | | | | | | | | | | | | 1 | | | | | |
| [48] | Frugal | 1 | | | | | | | 1 | | | | | | | | | |
| [49] - 3 cases | Frugal | | | 3 | | | | | 3 | | 3 | | 3 | 3 | | | | |
| [50] | Circular | | | | | | | | 1 | | | | | 1 | | | | |
| [51]- 1 case | Circular | | | 1 | | | | | | 1 | 1 | | 1 | 1 | | 1 | | |
| [36] | Circular | | | | | | | | 1 | | | | 1 | | | | | |
| [35] | Circular | | | 1 | | | | | 1 | | | | | | | | | |
| [52]- 16 cases | Circular | | | | | | | | 16 | | | | | 16 | | | | |
| [26]- 1 case | Circular | | | 1 | | | | | 1 | | | | | 1 | | | | |
| [53] | Circular | | | | | | | 1 | 1 | | | | 1 | 1 | | | | |
| [54]- 17 cases | Circular | | | | | | | | 17 | | 17 | | | 17 | | | | |
| [27]- 1 case | Circular | | | 1 | | | | | 1 | | | | 1 | 1 | | | | |
| [55] | Frugal | 1 | | | | | | 1 | | | 1 | | | | | | | |
| [37] | Circular | | | | | | | | 1 | | 1 | | 1 | 1 | | | | |
| [57] | Circular | | | | | | | | 1 | | | | | 1 | | | | |
| [23]- 1 case | Frugal | | | | | | | | | | | 1 | | | | | | |
| [27] | Circular | | | 1 | | | | | 1 | | | | 1 | 1 | | | | |
| [65] | Frugal | | | 1 | 1 | | | 1 | | 1 | 1 | | 1 | 1 | | 1 | | |
| [68] | Frugal | | | 1 | | | | | | | | | | | | | | |
| [69] | Frugal | 1 | | | 1 | | | | 1 | 1 | | | | | | | | |
| [70]- 4 cases | Frugal | 4 | | 4 | | | | | 4 | 4 | | | 4 | | | | | |
| [72] | Frugal | | | | | | | | | | | 1 | | | | | | |
| [73] | Circular | | | | | | 1 | | 1 | | | | 1 | 1 | | 1 | | |
| [25]- 13 cases | Frugal | 13 | | | | 13 | | | 13 | 13 | | 13 | 13 | | | | | |
| **Total** | | 26 | 1 | 14 | 2 | 13 | 1 | 5 | 73 | 20 | 27 | 15 | 31 | 55 | 0 | 3 | 0 | 0 |
| **Percentages** | | 9.1 | 0.4 | 4.9 | 0.7 | 4.5 | 0 | 1.7 | 36 | 7 | 9.4 | 5.2 | 11 | 19 | 0 | 1 | 0 | 0 |

Table 6: Measuring the sustainable dimensions from SDGs

### 3.7 Trends based on keyword co-occurrence and sectorial distribution

The network visualization of keyword co-occurrences was created by using VOSviewer[5]. In the network visualization as shown in Figure 1a, the strength and linkages between the keywords are expressed by the help of lines between them. It can be seen that CE relates to bioeconomy, sustainability, emerging markets, closed loops and recycling. FI is connected to sustainability, business models and emerging markets.

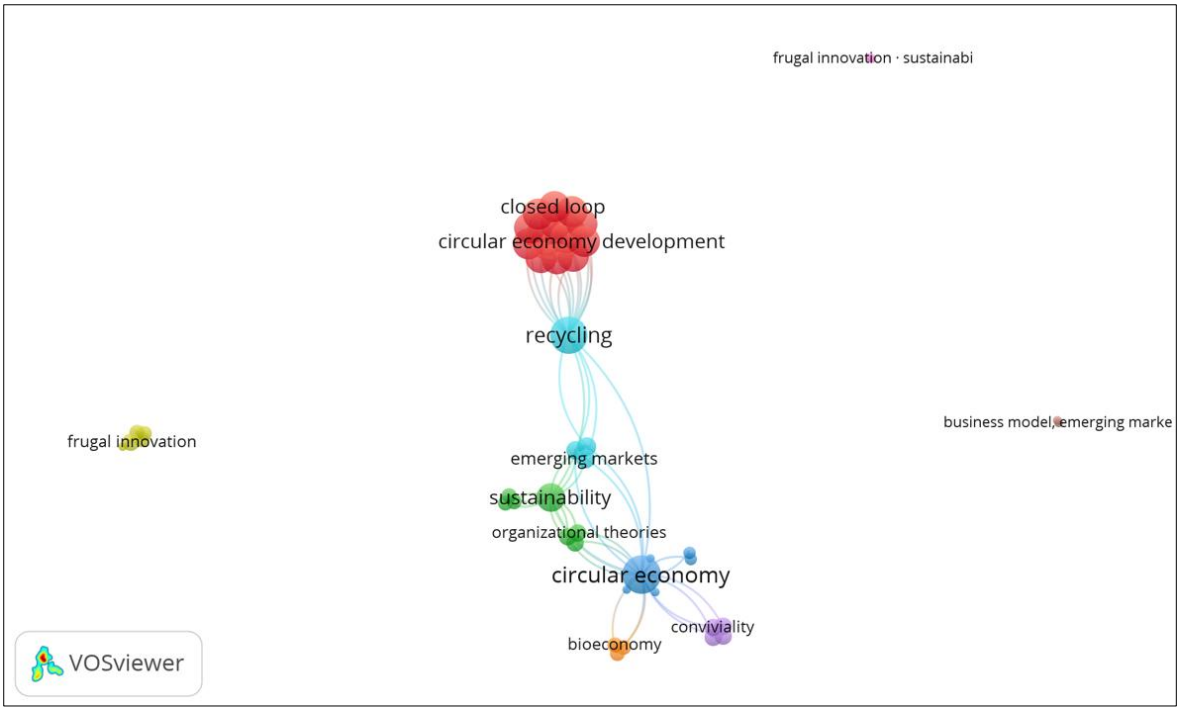



Figure 1a: Network Visualization map by VOSviewer

In Figure (1b), the density visualization of keyword co-occurrences also makes the connections easier to understand. In the density visualization, keywords are represented with the help of the nodes, and the density of the nodes is dependent on the keyword values surrounding them. If the density of the node is higher, it is represented by a brighter colour indicating as a high focus area of research. Lower density is shown with a light colour closer to blue indicating that the topic is relatively of low importance as compared to the brighter topics. In the figure 1b, the bright yellow region around circular economy indicates the highest keyword frequency and strongest research emphasis with closely associated terms such as “design”, “sustainability”, “emerging markets”, “circular economy development”, “recycling”, “closed loop.” This illustrate that most scholarly literature revolves around these interconnected concepts. Compare to that frugal innovation appears isolated with no overlaps and associations. This suggests clear research gap between frugal innovation and circular economy and highlights the need for further investigation in this area.

[5] See https://www.vosviewer.com/

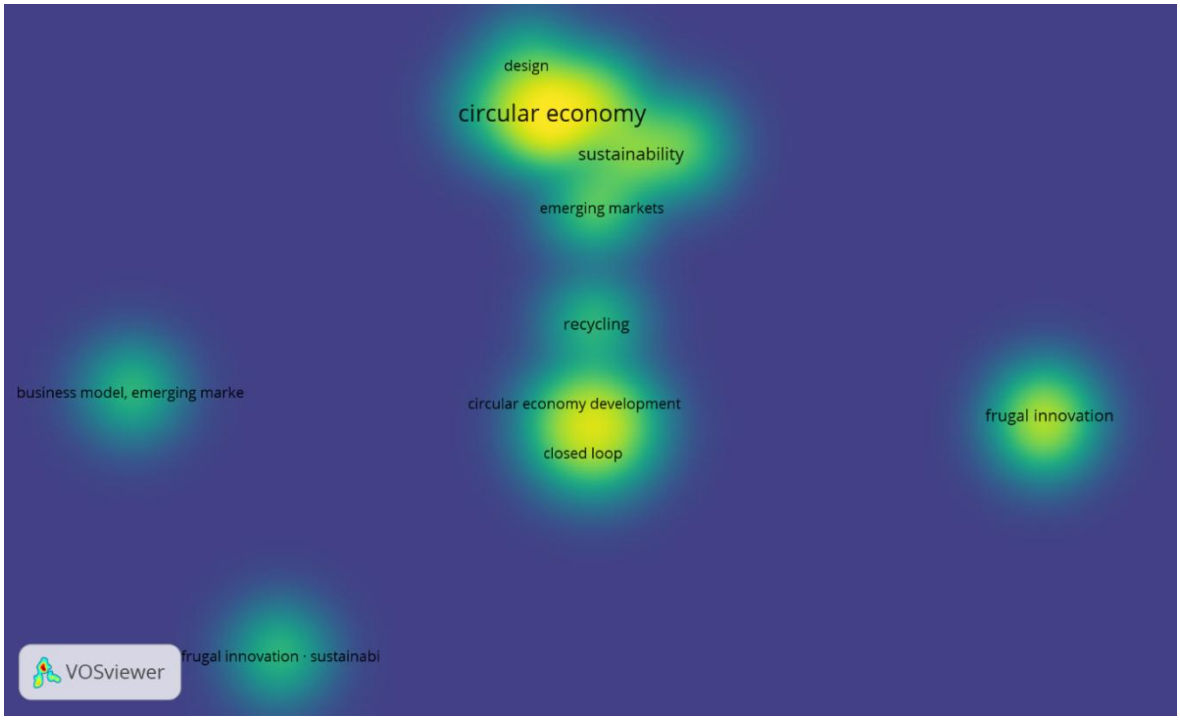



Figure 1b: Density Visualization by VOSviewer

From our study it has been observed that most of the cases are from EU, Africa and Asia (Figure 1c). In terms of industry, the most influential industry among our cases is food industry, consumer goods and healthcare (Figure 1d).

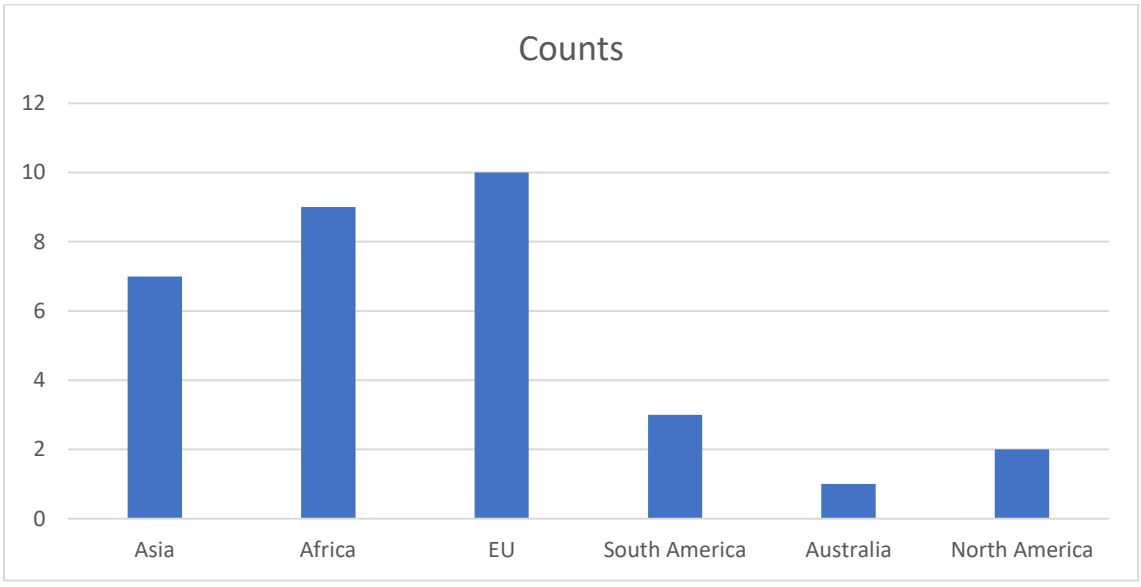



Figure 1c: Research Trends with respect to continents

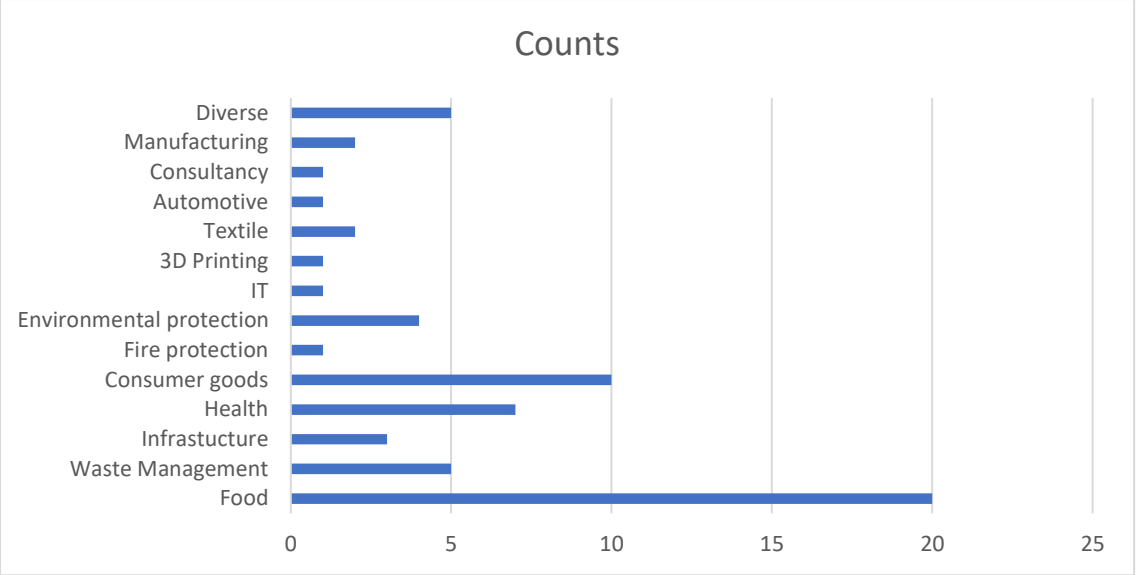



Figure 1d: Research Trends with respect to industry

## 4. Detailed Analysis

This section presents an analysis of the results using MAXQDA. Section 4.1 focuses on frugal innovation, while section 4.2 addresses the circular economy. Section 4.3 explores the intersection of frugal innovation and circular economy. Lastly, section 4.4 bridges frugal innovation and circular economy with respect to sustainability. To avoid misconceptions, and to enhance clarity we have limited the number of figures in the main text, therefore the figures related to Section 4.3 have been placed in the Appendix.

### 4.1 Frugal Innovation

Based on the findings derived from the qualitative content analysis of the studies related to FI, the economic dimension includes 64 codes, the environmental dimension contains 44 codes, the social dimension contains 43 codes, and the integrated dimension contains 20 codes. Considering subcategories, social inclusion and wellbeing rank highest with 19 codes, followed by ensures equal access to goods and services and local opportunities with 15 codes, value to low-income consumers with 14 codes, and business growth or revenues with 10 codes.

Among the economic dimensions, local opportunities rank highest, followed by value to low-income consumers. Moderate emphasis on business growth or revenues, low cost of raw materials and increase GDP and employment opportunities. In contrast, there is a very low emphasis on green supply chains / redesigning the supply chains, and competitive business models. This shows that frugal innovation is a mechanism for strengthening local economies by creating opportunities locally for the market and providing value to low-income consumers. In short, frugal innovation focused on local opportunities and cost-effective solutions to increase market inclusion, rather than green supply chain transformation and competitive business models. See Figure (2).

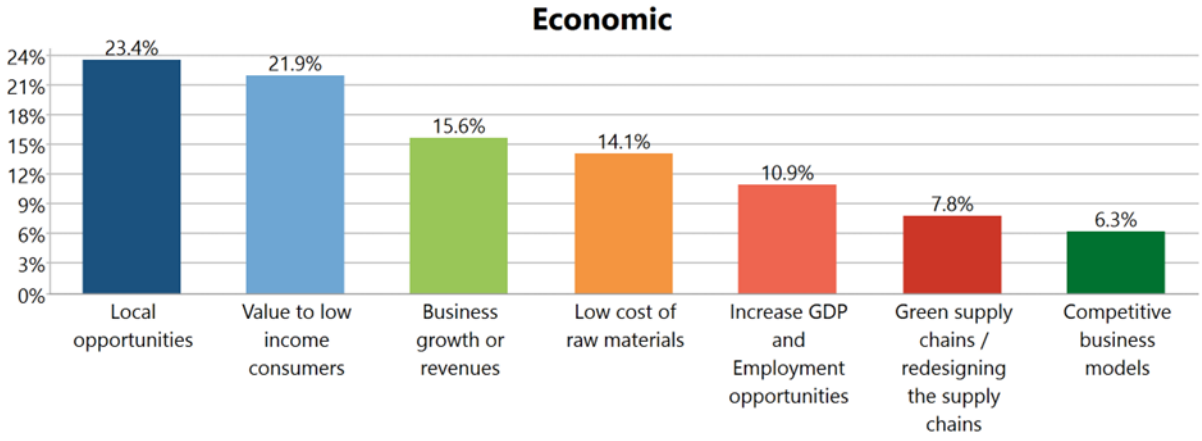



Figure 2: Economic Dimension of Frugal Innovation

Among the social dimensions of FI, social inclusion & wellbeing is the most remarkable outcome. Ensuring equal access to goods and services for both rich and poor emerged as a prominent theme. However, relationship with customers, providing new educational opportunities, philanthropic work for society, receive minimal emphasis. It can be observed that frugal innovation focused on affordability and equitable access of products and services for underserved population, it has no contribution towards improvement in brand image and reputations See Figure (3)

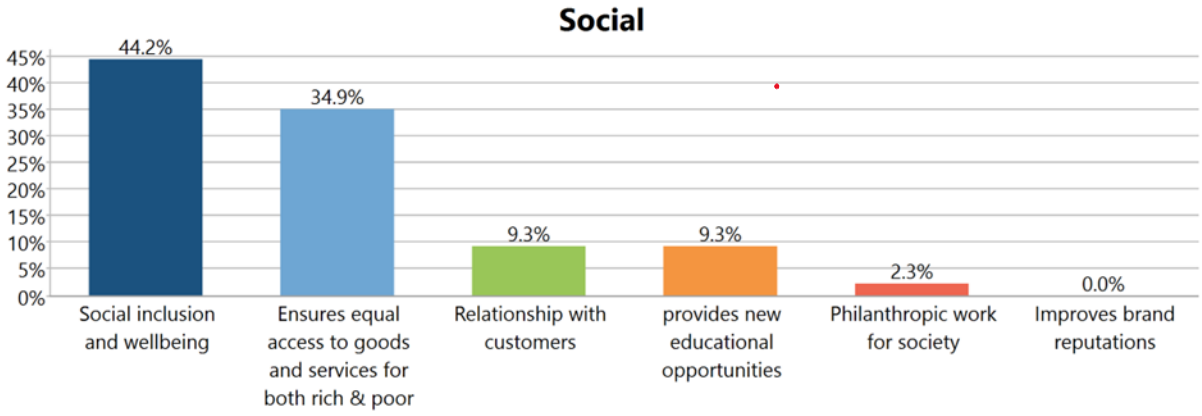



Figure 3: Social Dimension of Frugal Innovation

Among the environmental dimensions, less emissions and waste management both rank highest followed by reducing the use of physical resources and environment friendly production and consumption. Less emphasis on renewable energy and low dependence on virgin materials and noise mitigation and healthy environment frugal innovation focused on using fewer resources which contributes to less emissions and waste management. See Figure (4)

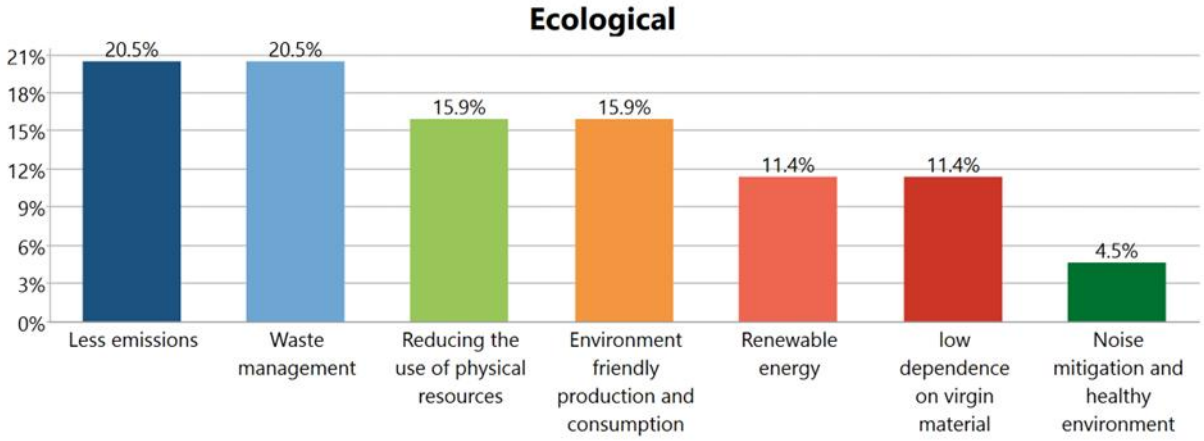



Figure 4: Environmental Dimension of Frugal Innovation

Among the integrated dimensions, social and economic, ranks highest. It shows that frugal innovation focuses more towards social and economic combination of sustainability. Moderate emphasis on economic and environmental, and social and environmental aspects and less emphasis on social, economic and environmental. Frugal innovation contributes towards societal well-being by bringing inclusiveness and delivers economic value through low-cost solutions See Figure (5).

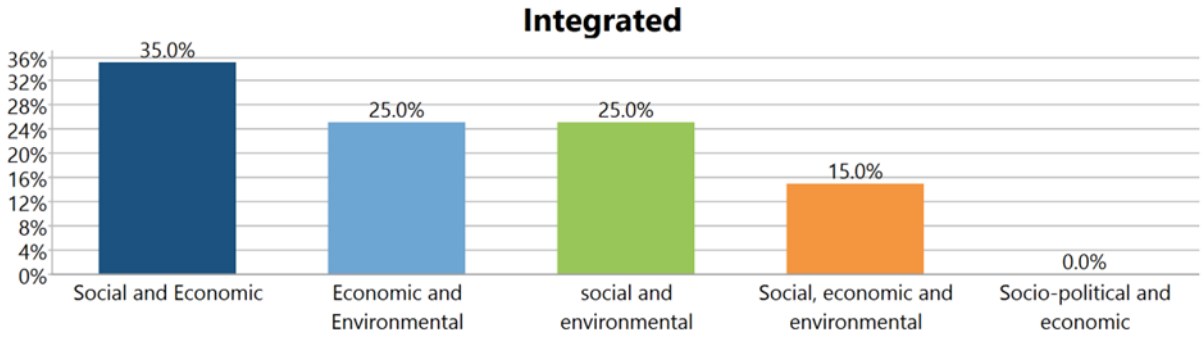



Figure 5: Integrated Dimension of Frugal Innovation

### 4.2 Circular economy

According to the qualitative content analysis of the studies related to CE, the economic dimension includes 40 codes, the environmental dimension contains 56 codes, the social dimension contains 11 codes, and the integrated dimension contains 23 codes. Considering subcategories, waste management ranks first with 16 codes, followed by environment friendly production and consumption with 13 codes, increased GDP and employment opportunities and low cost of raw materials with 10 codes, and 9 codes for low dependence on virgin materials and 8 codes for economic and environmental subcategories.

Among the economic dimensions, increased GDP and employment opportunities, and low-cost of raw materials rank highest. Moderate emphasis on business growth or revenues and local opportunities. Less emphasis on competitive business models and green supply chains / redesigning the supply chains and value to low-income consumers. The results shows that circular economy contributes towards macroeconomic outcomes and reduction in cost of raw materials. Circular economy is about closing the material loop and increasing the life span of the material at hand which ultimately reduces the cost of materials See Figure (6)

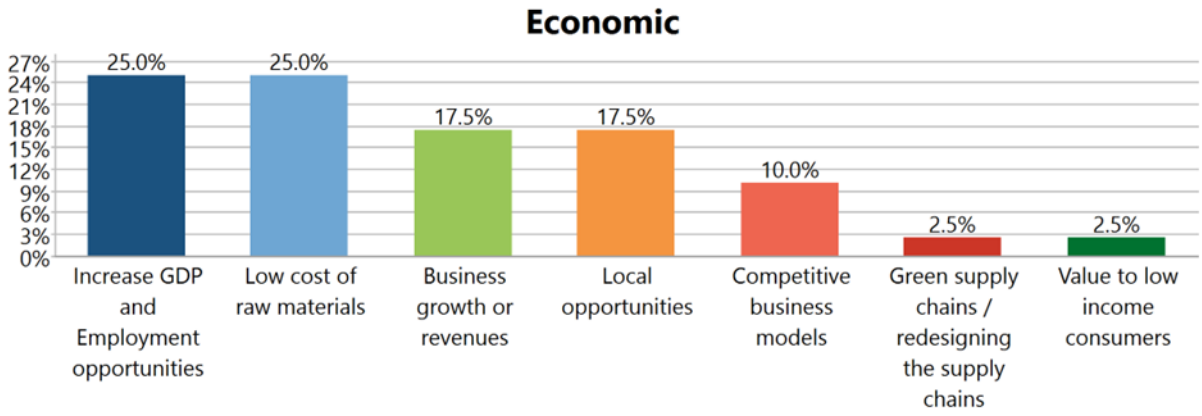



Figure 6: Economic Dimension of Circular Economy

Among the social dimensions, social inclusion and wellbeing rank highest. Moderate emphasis on improving brand reputation and philanthropic work for society. The results show that circular economy enhances the social inclusion and well-being of society by considering waste management and resource efficiency See Figure (7)

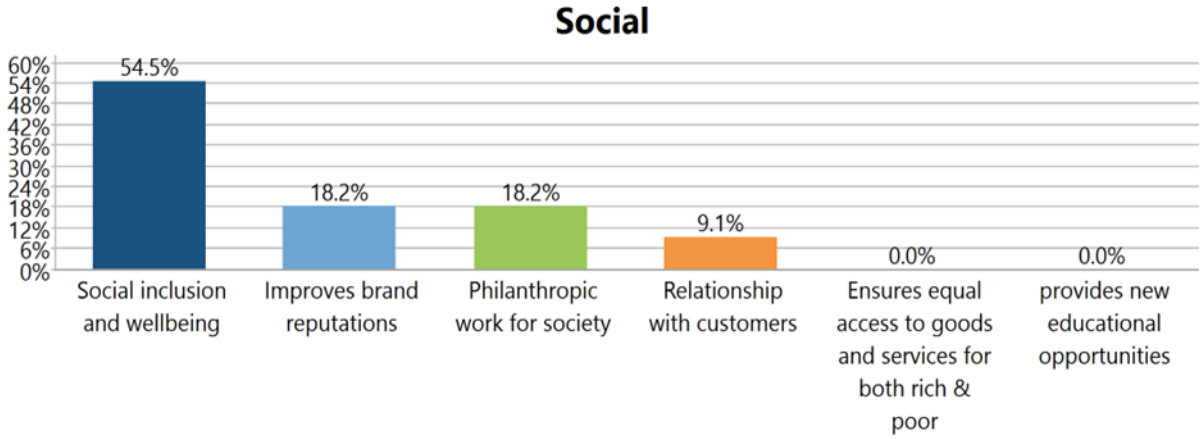



Figure 7: Social Dimension of Circular Economy

Among the environmental dimensions, waste management ranks highest followed by environment friendly production and consumption. Moderate emphasis on low dependence on virgin materials, less emissions (, and noise mitigation and healthy environment. Low emphasis on renewable energy. The results show that circular economy considers waste reduction and cleaner production and consumption while limited focus on noise mitigation and energy transformations. See Figure (8)

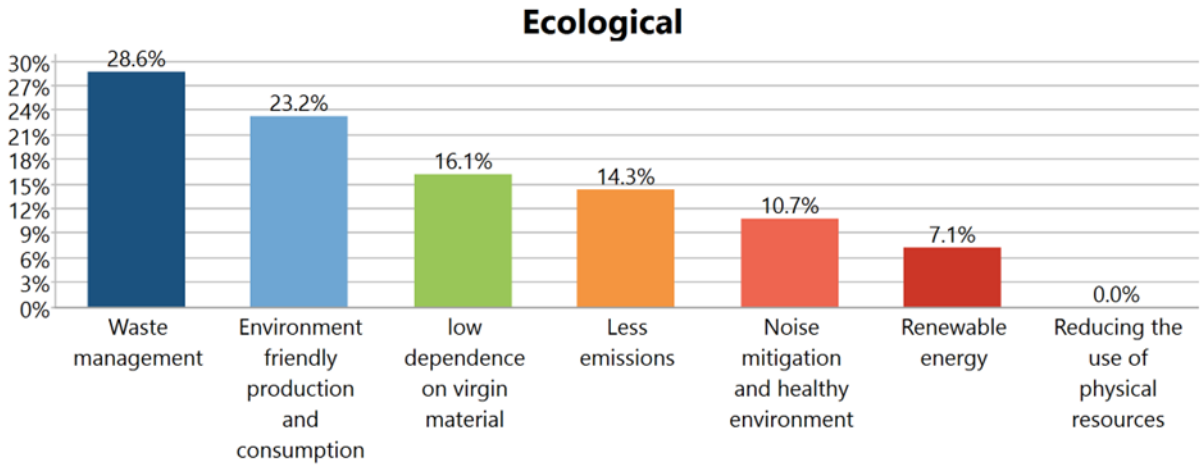



Figure 8: Environmental Dimension of Circular Economy

Among the integrated dimensions, economic and environmental rank highest followed by social, economic, and environmental. Moderate emphasis on social and environmental, social and economic, and less emphasis on socio-political and economic aspects. The results show that circular economy focuses more on resource efficiency and economic gains which aligns perfectly with its core principles of waste minimization and resource optimization. It has minimal association with political, or governance setting and mainly concerned with overall sustainability See Figure (9)

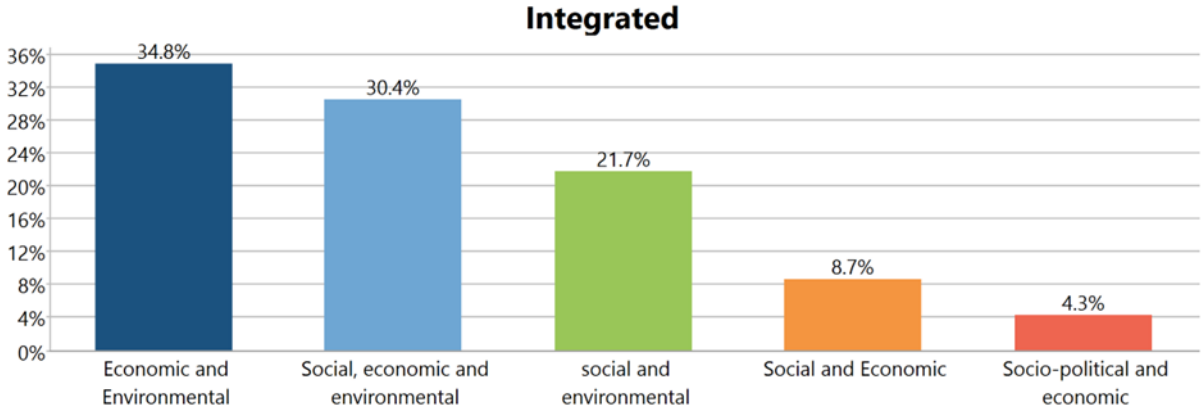



Figure 9: Integrated Dimension of Circular Economy

### 4.3 Frugal Innovation and Circular Economy

According to the overall qualitative content analysis of the study, the economic dimension includes 104 codes, the environmental dimension contains 100 codes, the social dimension contains 54 codes, and the integrated dimension contains 43 codes. Considering subcategories, waste management and social inclusion rank first with 25 codes, followed by local opportunities with 22, environment friendly production and consumption with 20 codes, and business growth and revenues with 17 codes.

The combination of frugal innovation and circular economy places strong emphasis on local opportunities and low-cost raw materials, reflecting the strengthening of local value chains and local production. Frugal innovation fits well with the efficient use of resources, while circular economy focuses on reusing materials available at hand. The combination supports business growth and contributes to GDP and creates new employment opportunities in the market, however it places less emphasis on competitive business models and green supply-chain or redesigning the supply chains. See Figure (2a in appendix)

The combination of frugal innovation and circular economy emphasizes social inclusion and wellbeing and ensures accessibility of goods and services for both rich and poor people. Together, it places lower emphasis on relationships with customers, new educational opportunities, philanthropic work for society and in enhancing the brand image of the product or service. See Figure (3a in appendix)

The combination of frugal innovation and circular economy produces higher emphasis on waste management and environmentally friendly production and consumption. Improvement in waste management by using limited resources and through reusing and closing the material loop which is an important aspect of circular economy. Moderate emphasis on less emissions and low dependence on virgin materials and low emphasis on renewable energy, noise mitigation and healthy environment and on reducing the use of physical resourcesSee Figure (4a in appendix).

The combination of frugal innovation and circular economy produces higher impact on economic and environment. Moderate emphasis on social, economic and environmental, social and environmental and social and economic integrated dimensions. Less emphasis on socio-political and economic dimension. The results show that combining frugal innovation with the circular economy is primarily viewed as a mechanism for achieving economic and environmental sustainability, while the social dimension is considered secondary. See Figure (5a in appendix)

### 4.4 Bridging frugal innovation and circular economy for Sustainability

The UN has adopted sustainability as a core principle for economic, environmental, and social progress, aiming to meet present needs without compromising the ability of future generations to meet their own needs. Sustainability is recognised as a key guiding principle for modern society, emphasising the ethical responsibility of current generations towards the future. Sustainable growth is also recognised as being socially equitable and ethically acceptable [77]. This pinpoints an equitable distribution of environmental costs and benefits of economic growth both within and across the nations, with an emphasis on CE and FI as strategic priorities [78].

The CE unquestionably holds substantial sustainability potential. Yet, due to a lack of solid theoretical foundation and a weak link to sustainable development, certain CE solutions have been proposed that negatively impact sustainability [91]. CE has been utilized for financial reasons for centuries without protection of the environment. Industrial history is filled with instances of industrial symbiosis, which is closely related to CE, where the by-products of one industry are utilized as inputs for another with the intention of waste reduction. Industrial symbiosis can be sustainable, but they may also reinforce unsustainable material systems, like the petrochemical industry infrastructure, which is seen as crucial for social and economic reasons, thus maintaining a reliance on fossil fuel extraction [79]. When residual waste is diverted from landfills to thermal waste-to-energy processes, it releases carbon emissions from materials, hinders recycling efforts, and increases dependency on raw materials in the economy. In many instances, the broader trade-offs associated with CE activities may not justify the sustainability advantages [80]. FI is best examined as a distinct invention method that occurs at many societal levels and involves a wide range of actors collaborating in different ways. Power dynamics and conflicts remain critical factors in determining the influence of FI methods on people's lives. Examining FI from a development perspective highlights the localised innovation practices of impoverished individuals and connects them to the historical discourse in development studies regarding the significance of innovation, technology, and bricolage in survival and livelihood strategies. This requires a thorough analysis of the concept of FI, its dynamics, and its developmental significance. One study [81] presented initial concepts for analysing the dynamics and possibilities of FI for development in a recent publication.

The operational processes described for CE such as waste management gears towards providing a healthier environment, while operational processes such as innovative production in FI are focussed on economic and social perspective. Approaches attempting to balance the three pillars of sustainability have faced criticism due to the challenge of comparing values such as biodiversity, landscape beauty, costs, profitability, equity, health, and cultural values, which are not clearly commensurable. Conflicting interests among stakeholders often arise within a single sustainability aspect, such as social, economic, or environmental issues. Balancing these interests within one aspect may take precedence overachieving a balance across all three aspects.

The results of our analysis are shown in the figure (10) below. On the left side we have included sustainability dimensions- economic, social and ecological. On the upper right side, we have circular economy and on the lower right side we have frugal

innovation. the two concepts. Circular economy, related closely to ecological dimension of the sustainability (particularly with waste management and environmentally friendly consumption and production) begins with products, services, desired outcomes i.e. waste management, increase in dividends, better environment and economic performance. CE enhances economic performance by increasing GDP and employment opportunities, increasing business growth and revenues and by closing the material loops through low-cost material selection and techniques.

consumption and stakeholders' preferences. It progresses through enablers such as policies, indicators, limitations, and capabilities and then lead towards the

Frugal Innovation, on the other hand, considers innovative technologies to produce affordable solutions. Digital enablers such as big data, artificial intelligence etc results into positive impact in the operational areas such as manufacturing, logistics, operations etc. It results into sustainable solutions which are affordable and include resource efficient procedures. Both

concepts independently contribute to sustainability; however, when integrated together, they complement one another and generate synergetic effects. Frugal innovation support circular economy by introducing sustainable simpler design and affordable solutions and circular economy supports

frugal innovation in achieving scalability and efficiency. Therefore, the integration of CE and FI strengthens the sustainability by fostering inclusiveness, promoting social well-being, supporting environmental stewardship and economic resilience.

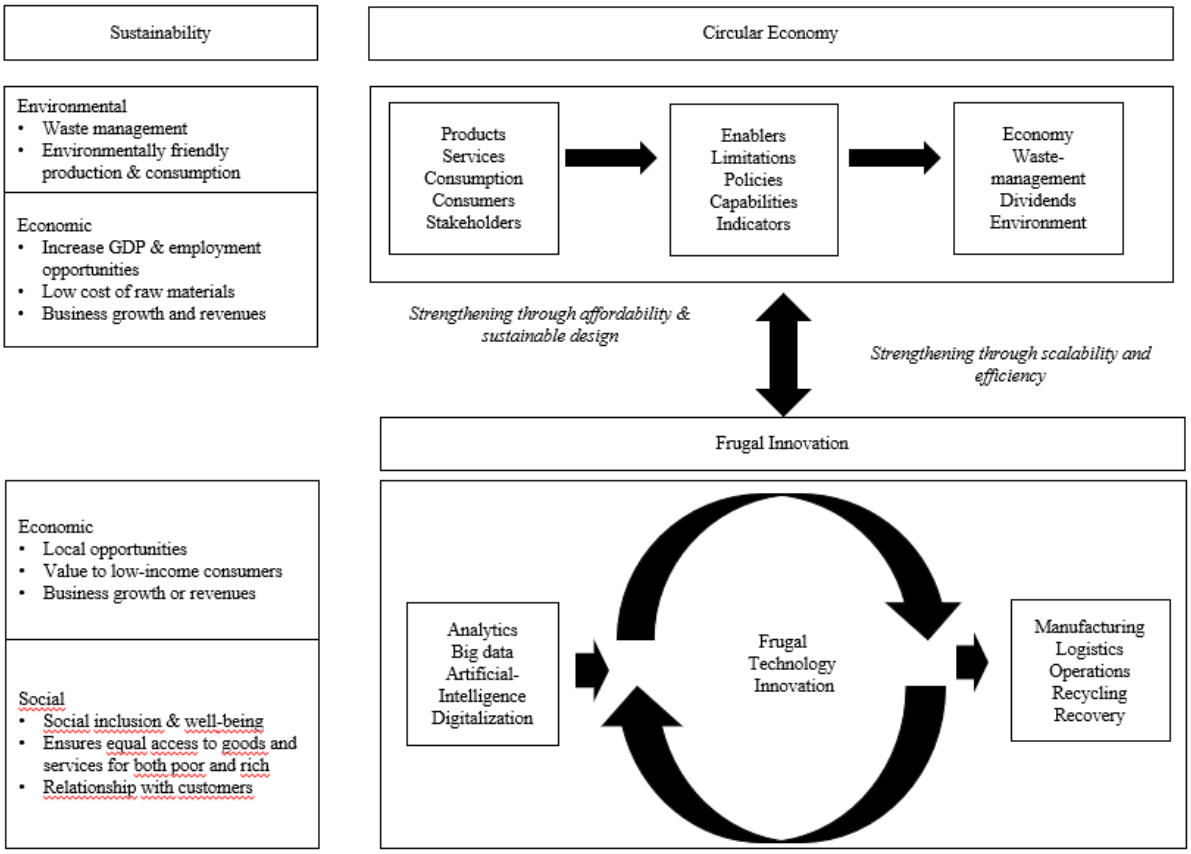



Figure 10: Interaction between frugal innovation, circular economy and sustainability

## 5. Discussion and Implications

This section presents the discussion and conclusion of the study followed by implications, limitations and future research direction. The primary objective of this study was to address the following research question: What are the connections and interlinkages between CE and FI, and how do they impact sustainability? For this, previous literature was reviewed to identify the relevant indicators.

Our findings align with the limited number of studies in which the collaboration between FI and circularity has been recommended. We proposed that frugality must be combined with the concept of CE for achieving environmental sustainability and inclusivity [43]. FI could act as a catalyst for the CE, since the principles of the CE overlap with those of FI, as explained in one of the cases that the use of a frugal approach to solar energy can contribute to circular products and environmental sustainability goals [22]. Furthermore, the utilization of repurposed materials is an essential element of FI, as it helps mitigate waste generation in accordance with the principles of the CE. Therefore, it is imperative to emphasize partnerships between CE and FI at all levels in order to solve the world's problems together [41]. Moreover, embracing a CE provides FI with the potential to foster the development of new markets and contribute to building a more sustainable and inclusive world [48]. Frugal innovation and circular economy support each other in developing sustainable low-cost solutions with the potential of scalability and environmental legitimacy.

These results are logical since FI is all about cost reduction and minimal usage of inputs with optimized performance level of product or service. The idea of FI gains momentum from grassroot entrepreneurs who invented solutions to the problems of society, e.g., Miticool refrigerator which is a refrigerator made up from clay and runs from the technique of water evaporation and therefore fulfills the needs of poor people in the villages with no availability of electricity. FI introduces poor people to the market which were not part of the market before because of the fewer monetary resources. Although FI is already contributing towards the economic, environmental, and social dimensions of sustainability in the whole world, there is still room for further development, specifically to save the health of the overall environment. For this, recent research presents approaches on how to develop FIs ex ante [82]. Climate change, natural resources depletion, and the

sixth mass extinction are casting dark shadows across the globe. CE provides a solution to these challenges by continuous reuse of products and materials in the entire value chain. This approach of reusing materials contributes towards the life cycle extension of products which eventually support in reducing waste and pollution [83]. CE is mainly related with slowing strategies which involves prolonging the usage of the products to maximize their lifespan while minimising the environmental effects [84]. It reduces the greenhouse gas emissions by carbon usage and in return mitigates the harmful effects on biodiversity. The most important goal of transitioning to CE is in contributing to reduced greenhouse gas emissions, decreased environmental impact, decreased use of resource, and growth in employment and increased value addition [85].

To conclude, circular economy originates from the consideration of products, services, consumption behaviours, and stakeholder preferences, and advances through a set of enablers i.e. policy frameworks, performance indicators, limitations, and capabilities, ultimately leading to outcomes such as improved waste management, enhanced environmental quality, and increased economic performance. Circular Economy contributes to economic sustainability by fostering GDP growth, increasing employment opportunities, and promoting business development, notably through closing the material loops and through resource-efficient practices. On the other hand, frugal innovation prioritizes the development of affordable, sustainable solutions through innovative technologies. The combined application of these approaches strengthens sustainability by promoting social inclusiveness, ensuring environmental stewardship, and enhancing economic resilience. Moreover, this combination of frugal innovation and circular economy enhances contribution towards achieving sustainable development goals particularly SDG no. 8 (Decent work and Economic growth), SDG no.12 (Responsible consumption and production), SDG no.13 (Climate action), SDG no. 1 (No Poverty), SDG no. 10 (Reduced Inequalities) and SDG no. 9 (Industry, Innovation and Infrastructure).

### 5.1 Managerial Implications

The findings of this research provide guidelines to the managers, policy makers, governments, researchers and the academic community about insights from FI and CE literature related to sustainability. Integrating frugal innovation and circular economy requires a fundamental transformation of traditional business models. Managers should integrate frugal design by making products simple, affordable without compromising on quality while simultaneously incorporating circular principles of reuse, reduce and recycle etc for waste minimization and closing the material loops. The study highlights the importance of local resources; therefore, managers should consider using local raw materials and resources for production which ultimately results in creation of local opportunities. This will ensure inclusivity of low-income consumers in the market and enhance the GDP. Managers must recognize the strategic significance of both concepts and establish partnerships across the entire value chain. To do so, requires continuous learning, acquisition of new knowledge, and the adoption of innovative approaches towards business operations. Managers should consider the importance of emerging markets which often serve as valuable sources of insight and practical experience in resource-constraints environment. For example, Multinational such as GE and Siemens have established R&D centres in India and China where they develop frugal innovation by leveraging local competencies. Siemens fetal heart rate monitor is an example of frugal innovation which was developed through these R&D centres. Managers should learn and take inspiration from these emerging economies to move beyond traditional business paradigms and enhance resource utilization and collaboration with internal and external stakeholders. The study shows that frugal innovation enhances scalability and affordability while the circular economy reinforces these benefits through resource efficiency and environmental gains. Managers should therefore integrate both these concepts from the initial phases of product conception and design to promote sustainability throughout the entire life cycle. Applying life cycle analysis at every stage will support in evaluating the environmental impacts and guide in making sustainable decisions. Although the concept of circular economy is still in its inception phase, recognizing and learning from existing good practices is crucial to its advancement. Trainings and education should be given on an ongoing basis to develop deep understanding of these concepts in the organizations. In asset intensive sectors managers should consider coordinating both concepts to strengthen resilience across economic and environmental dimensions. Managers should consider incorporating universities, NGOs, consultancy firms, and small and medium-sized enterprises (SMEs) into projects related to the circular economy to foster collaboration, stimulate innovation, and cultivate meaningful insights for sustainable development.

For governments and policymakers, the findings of this study offer critical insights into advancing the Sustainable Development Goals (SDGs) and

identifying areas where progress remains insufficient for instance, SDG no. 6 “Clean water and sanitation”; SDG no.4 “Quality education”; SDG no. 2 “Zero hunger”; SDG no. 15 “Life on land”; SDG no. 14 “Life below water”; SDG no. 16 “Peace, justice and strong institutions”, and SDG no. 17 “Partnerships for the goals. Governments should initiate programs that simultaneously promote frugal innovation and circular economy practices, as focusing on one without the other limits the potential for truly sustainable outcomes. Incorporating these concepts into national strategic goals can significantly strengthen environmental and economic resilience. For instance, Slovenia has put special emphasis on circular economy in its recovery and resilience plan[6] [2021-2026] and in its national development strategy [2030][7], which explains its position as a leading performer in circular economy implementation. Governments should support research and development projects that combine frugal innovation and circular economy principles, with a particular focus on the manufacturing and automotive sectors where the potential for sustainability transformation is substantial as highlighted in the study.

From a policy level, there is a need to develop a conceptual framework integrated with the United Nation (UN) SDGs that are directly supported by circular economy and frugal innovative initiatives. Collaboration among academia, industry, and government is essential to operationalize this integration effectively.

From the industrial perspective, our research provides insights on how to achieve sustainability in the respective industries by experimenting with the theories of FI and circularity. In the end, it is very important that all stakeholders, including government, industry, and academia, must collaborate to promote circularity in combination with FI in their respective strategies and policies. Here, it will be key that there will be a cohesion process in the academic discussion. To date, too many different disciplines, countries and communities are working on the same phenomenon without bearing the other ones in mind. This is somehow normal at the beginning of the discussion of a new topic. But over time, it is necessary to develop a common understanding of terms and interlinkages [87] so that a scientific discussion can also emerge into a discussion with and for policy makers and industry practitioners.

### 5.2 Limitations and Future research directions

Although our study presented the conceptual relationship between frugal innovation, circular economy and sustainability, further empirical and evidence-based research is necessary to validate and deepen these insights [88]. There are various limitations in this study. English language articles are considered in the study and therefore there might be a possibility of exclusion of several important aspects related to FI and CE from the diverse type of literature in different languages. The same is true for the choice of sources, as well as the focus on academic outlets only.

Future research could investigate deeper into the concept of CE business models [89] for instance with more supply chain collaboration [90]. Additionally, combination of CE and digital capabilities which creates value to the customers in small and medium enterprises has already been investigated, but adoption of digital technology to enable circular business models in small and medium enterprises is another important topic for research and needs further investigation [91]. The context of the pandemic specifically the COVID-19 pandemic offers several initial points for future research on CE and sustainability [92] which could also be interesting to fellow researchers. Some biasedness can be assumed from the values of TBL dimensions of sustainability. The values for TBL dimensions were assigned to case studies or empirical papers only and some of the articles included in the study are conceptual papers. Therefore, there is a need to consider the conceptual papers in depth separately and identify the TBL dimensions values for sustainability from every single unit. In the end, a comparison can be made between the conceptual papers and the empirical cases with respect to TBL dimensions of sustainability. This can be considered as one of the future research directions. Furthermore, we have not considered Google Scholar in our search engines. There might be some interesting text available there with reference to FI and CE. In the study, 47 articles were considered for final review and therefore there is a need to review a broader sample either through the inclusion of some other keywords like “eco-innovation”, “green innovation”, “green economy”, “blue economy”, “frugal engineering”, open innovation etc., or by considering other search

[6] https://www.gov.si/en/registries/projects/the-recovery-and-resilience-plan/

[7] https://www.gov.si/assets/ministrstva/MKRR/Strategija-razvoja-Slovenije-2030/Slovenian-DevelopmentStrategy-2030.pdf

engines and platforms, e.g., Google Scholar. The perception of FI and CE has great potential in overall minimizing the harmful impacts on the environment, economy, and society. Collaboration is needed at every step to achieve sustainability and peace in the entire world. There is a dire need to write about the good practices, cases and procedures of CE followed in society. Dissemination of these good practices of CE and FI will eventually create a larger impact in achieving the United Nation (UN) Sustainable Development Goals (SDGs). Future research is needed in identifying, classifying, and reporting the good practices of CE and FI that are going on in different territories in the world. Diffusion of CE and FI is another interesting research field. In addition, how to change the mindset of organizations towards circularity and FI has a significant importance in research. Lastly, consumer perspective in adopting circularity and FI is also an interesting future research topic.

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## Appendix

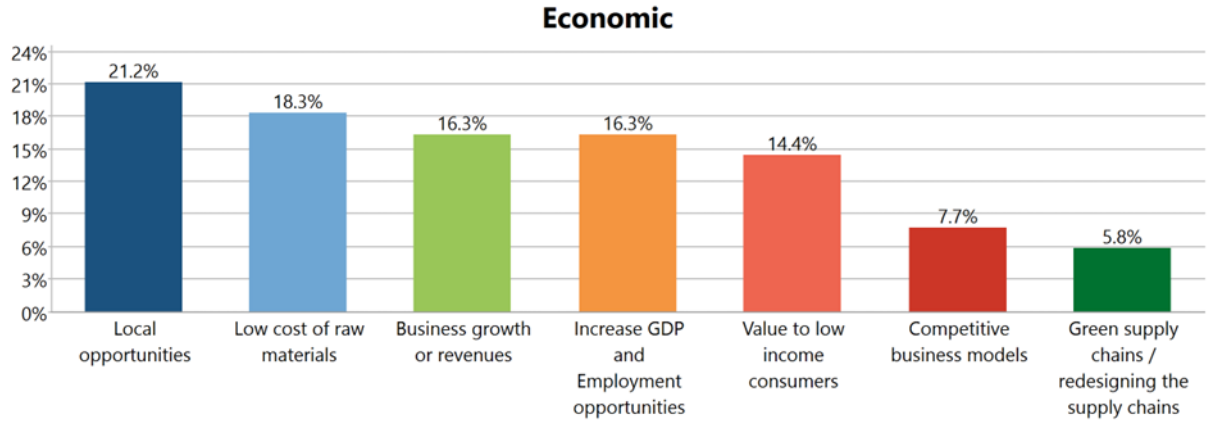


Figure 2a: Economic Dimension of Frugal Innovation and Circular Economy

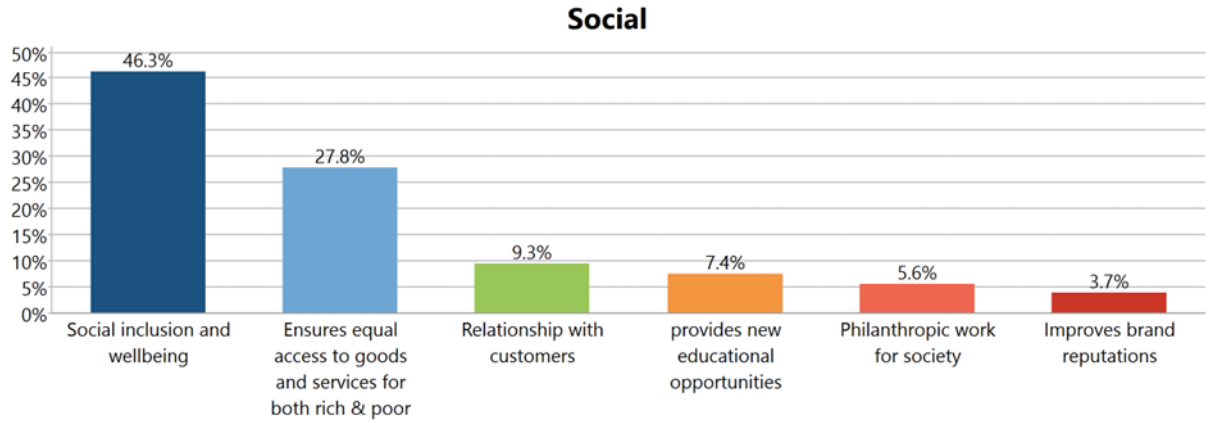


Figure 3a: Social Dimension of Frugal Innovation and Circular Economy

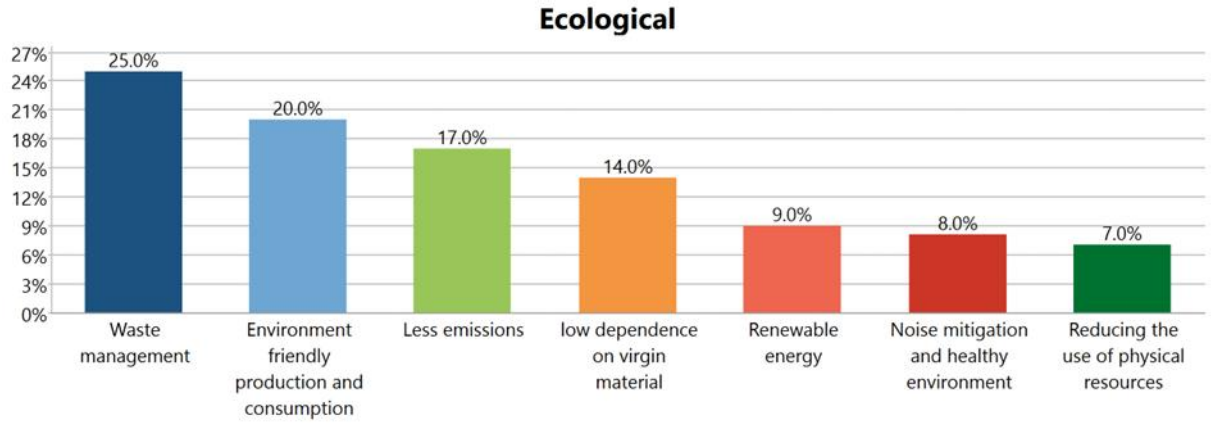


Figure 4a: Environmental Dimension of Frugal Innovation and Circular Economy

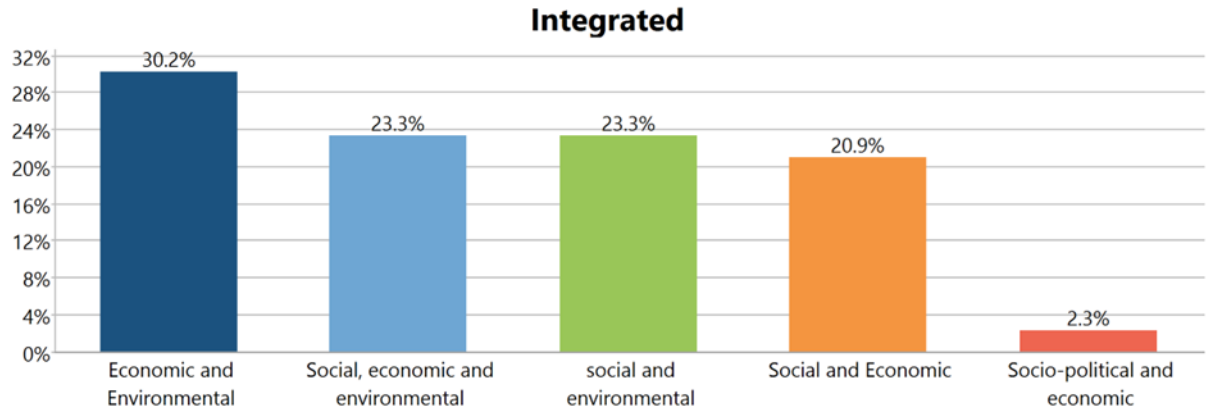


Figure 5a: Integrated Dimension of Frugal Innovation and Circular Economy