

**UNIVERSITY OF BAHRAIN**

College of Science



Environment and Sustainable  
Development Program

# **The Role of Urban Food Waste Management Toward Achieving Sustainable Development**

A Thesis Submitted in Partial Fulfilment of the Requirements for the  
Ph.D. Degree in Environment and Sustainable Development

**Submitted by**

**Shahrah Saad Saeed Alqahtani**

University ID: 202012465

**Supervised by**

**Dr. Ahmed Abdelfattah**

Associate Professor

University of Bahrain

**Kingdom of Bahrain**

**May, 2024**

# Defense committee's approval

University of Bahrain  
Deanship of Graduate Studies  
And scientific Research



جامعة البحرين  
مجلس الدراسات العليا والبحث العلمي

## Thesis Discussion Committee Decision

|                                                                                                          |                              |
|----------------------------------------------------------------------------------------------------------|------------------------------|
| Student Name: <b>SHAHRAH SAAD SAEED ALQAHTANI</b>                                                        | Student ID: <b>202012465</b> |
| Department: Choose an item.                                                                              | College: <b>Science</b>      |
| Program: <b>PhD in Environment and Sustainable Development</b>                                           |                              |
| Thesis Title:<br><b>The Role of Urban Food Waste Management toward Achieving Sustainable Development</b> |                              |
| Supervisor Name: <b>Dr. Ahmed Abdelfattah</b>                                                            | Student GPA: <b>3.76</b>     |

The Discussion Committee met on 02-May-24 In College of Science – Room S41-0002. Upon discussing the student whose details are stated above in public, the discussion committee recommends the following:

The student is awarded a grade “pass” in the thesis subject.

☐ Without making any changes to the thesis.

☒ After making the modifications attached with this decision.

Discussion Committee Members Approval:

Name

Signature

1. Dr. Ahmed Abdelfattah (Advisor)
2. Dr. Qaisar Mahmood (Internal Examiner)
3. Prof. Abda Emam (External Examiner)

6 | Approved at the University Council 6th meeting, 2013  
In accordance with Decision No. 736/2013 dated 14/3/2013  
Modified by University Council Decision No. 2043/2013 dated 20/11/2013.

## **Abstract**

This study endeavours to investigate the sustainable availability of food waste management (FWM) in Saudi Arabia, shedding light on its role in achieving sustainable development objectives. The primary focus lies on examining the current FWM practices within Khobar City, Saudi Arabia, while elucidating the factors, challenges, and potential limitations that impact FWM. The study identifies five specific objectives aimed at enhancing efficiency and fostering sustainability within the Kingdom of Saudi Arabia's (KSA) FWM.

The objectives involve estimation of public awareness, knowledge, and attitudes regarding FWM, as well as analysing the roles, interactions, and perspectives of stakeholders of Saudi Arabia's KSA-FWM. The aim is to foster guidance and provide recommendations that can contribute to reducing FW generation and its environmental impacts through employing innovative management options. Through the systematic execution of these objectives, the research endeavours to comprehensively dissect of FW management practices in Al-Khobar City, Saudi Arabia, with a view towards identifying critical determinants, challenges, and potential avenues for enhancing efficiency and sustainability within the ambit of FW management initiatives.

The research is divided into five distinct chapters. The first chapter, as the introductory chapter, lays the foundation for the research inquiry encapsulating key elements including research questions, identified problems, the purpose and significance of the study, and an outline of the research structure. Second Chapter delves into an extensive review of the literature related to FW production dynamics, environmental ramifications, and social and economic implications. Additionally, it examines current FW management practices within the KSA, juxtaposed against global sustainable management alternatives, strategies, and existing methodological tools aimed at fostering sustainable FW management. The third chapter provides methodological procedures required in achieving the aims and objectives of the study. It includes diverse methodological approaches and phases, alongside the tools employed for data analysis. Surveys and questionnaires, field observations, and interviews with stakeholders spanning academia, retail sector, government officials, and consumer demographics were conducted.

The fourth chapter presents the results and discussions derived from the preceding third chapter. It describes an assessment of public awareness through statistical analysis. It

provides the Food Waste Management Decision Tree (FWMDT) framework to classify seven types of FW prevalent in the retail industry and link them to different sustainable FWM options. Furthermore, the chapter elaborates on the development of simulations and scenarios predicated upon a comprehensive array of variables and factors, incorporating insights from local stakeholders. This approach serves to facilitate strategic planning and decision-making by enabling local actors to articulate their perspectives while affording policymakers enhanced comprehension of local imperatives, thereby reducing conflicts and increasing the effectiveness of final policy interventions. Lastly, the concluding chapter of the study encapsulates its contributions, describes its limitations, offers pertinent recommendations, and suggests avenues for future research endeavours.

In summary, the study concludes that Saudi Arabia has encountered challenges in attaining sustainable FWM in recent times, primarily attributable to the inadequacy of local stakeholders in guiding and overseeing FW practices in a sustainable manner. Nonetheless, the implementation of comprehensive government policies and strategies concerning FWM, when fully articulated and informed, presents a viable option for achieving sustainability in this domain.

## **Publications**

S. AlQahtani, S., Khan, E., Ahmed, A. E., & A. AlQahtani, M. (2024). **“Sustainable Management of Food Waste in Saudi Arabia”**. In Food and Nutrition Security in the Kingdom of Saudi Arabia, Vol. 2: Macroeconomic Policy and Its Implication on Food and Nutrition Security (pp. 215-239). Cham: Springer International Publishing.

## **Dedication**

I dedicate this thesis to my husband and our lovely children for their support, encouragement, and giving me the time to write up.

## **Acknowledgements**

I would like to express my deepest appreciation to all of those who supported me throughout this long journey . I would like to thank my academic supervisor Dr. Ahmed Abd El-Fattah for his follow-up. I am thankful and grateful for Dr. Adam Elhag Ahmed for his knowledge and reliable support especially during the book chapter publication.

## List of Abbreviations

|       |                                                         |
|-------|---------------------------------------------------------|
| FW    | Food Waste                                              |
| FWM   | Food Waste Management                                   |
| FWH   | Food Waste Hierarchy                                    |
| FWMDT | Food Waste Management Decision Tree                     |
| AD    | Anaerobic Digestion                                     |
| AF    | Animal Feeding                                          |
| RD    | Redistribution                                          |
| C     | Composting                                              |
| TH-NR | Thermal treatment with energy recovery                  |
| FSC   | Food Supply Chain                                       |
| Mt    | Metric tones                                            |
| FCM   | Fuzzy Cognitive Map                                     |
| CFCM  | Community Fuzzy Cognitive Map                           |
| FAO   | Food and Agriculture Organization of the United Nations |
| UNEP  | United Nations Environment Programme                    |
| NGOs  | Non-governmental Organizations                          |
| WRAP  | Waste & Resources Action Programme                      |
| KFU   | King Faisal University                                  |
| KSA   | Kingdom of Saudi Arabia                                 |
| US    | United State of America                                 |
| UK    | United Kingdom                                          |
| EU    | European Union                                          |
| MEWA  | The Ministry of Environment, Water and Agriculture      |
| MWAN  | National Center for Waste Management                    |
| GFSA  | General Food Security Authority                         |
| SIRC  | The Saudi Investment Recycling Company                  |

# List of Contents

|                                                                               |    |
|-------------------------------------------------------------------------------|----|
| Defense committee’s approval .....                                            | A  |
| Abstract .....                                                                | B  |
| Publications .....                                                            | D  |
| Dedication .....                                                              | E  |
| Acknowledgements .....                                                        | F  |
| List of Abbreviations .....                                                   | G  |
| List of Contents .....                                                        | H  |
| List of Tables .....                                                          | L  |
| List of Figures .....                                                         | M  |
| CHAPTER 1 Introduction Of The Study .....                                     | 1  |
| 1.1. Introduction .....                                                       | 1  |
| 1.2. Research Problem .....                                                   | 4  |
| 1.3. Research Questions .....                                                 | 5  |
| 1.4. Research Aim and Objectives .....                                        | 5  |
| 1.5. Research Scope and Significance .....                                    | 6  |
| 1.6. Structure Of This Research .....                                         | 7  |
| 1.7. Chapter Summary .....                                                    | 8  |
| CHAPTER 2 Literature Review and Previous Studies .....                        | 9  |
| 2.1 Introduction .....                                                        | 9  |
| 2.2 Defining food wastage, a contentious issue .....                          | 10 |
| 2.2.1 Food surplus .....                                                      | 11 |
| 2.2.2 Food waste .....                                                        | 12 |
| 2.2.2.1 Avoidable FWs .....                                                   | 13 |
| 2.2.2.2 Nonavoidable FWs .....                                                | 13 |
| 2.2.3 Food Losses (FLs) .....                                                 | 13 |
| 2.2.3.1 Planned FL .....                                                      | 15 |
| 2.2.3.2 Unplanned FL .....                                                    | 16 |
| 2.2.3.3 Food loss during post-harvest .....                                   | 17 |
| 2.3 Previous studies-FWs in Saudi Arabia (KSA) challenges and solutions ..... | 18 |
| 2.4 FW and food security .....                                                | 26 |
| 2.5 Food waste & environmental impacts .....                                  | 29 |
| 2.6 Techniques to handle FW .....                                             | 33 |
| 2.6.1 Zero Hunger Hero Method .....                                           | 33 |

|                                                                               |    |
|-------------------------------------------------------------------------------|----|
| 2.6.2 Managing FW sustainably .....                                           | 34 |
| 2.6.2.1 The Food Waste Hierarchy.....                                         | 37 |
| 2.6.2.1.1 Reduction.....                                                      | 38 |
| 2.6.2.1.2 Reuse.....                                                          | 40 |
| 2.6.2.1.2.1 Redistribution .....                                              | 40 |
| 2.6.2.1.2.2 Animal Feeding .....                                              | 41 |
| 2.6.2.1.3 FW Recycling .....                                                  | 42 |
| 2.6.2.1.3.1 Anaerobic Digestion .....                                         | 42 |
| 2.6.2.1.3.2 Composting.....                                                   | 45 |
| 2.6.2.1.4 Recovery .....                                                      | 46 |
| 2.6.2.1.4.1 Thermal Treatments Induced Recovery of Energy.....                | 47 |
| 2.6.2.1.4.2 Land Spreading.....                                               | 48 |
| 2.6.2.1.5 Disposal.....                                                       | 48 |
| 2.6.2.1.5.1 Thermal Treatment Avoiding Recovery of Energy (Incineration)..... | 49 |
| 2.6.2.1.5.2 Landfilling .....                                                 | 49 |
| 2.7 Legislative Laws .....                                                    | 49 |
| 2.8 Circular bioeconomy.....                                                  | 51 |
| 2.9 Literature Conclusion.....                                                | 53 |
| 2.9.1 Executive summary of previous studies .....                             | 53 |
| 2.9.2 Chapter Summary .....                                                   | 55 |
| Chapter 3: Methods and Procedures .....                                       | 56 |
| 3.1 Introduction.....                                                         | 56 |
| 3.2 Research Strategy.....                                                    | 56 |
| 3.2.1 Analytical research.....                                                | 56 |
| 3.2.2 Fundamental research .....                                              | 57 |
| 3.2.3 Qualitative research .....                                              | 57 |
| 3.2.4 Quantitative research .....                                             | 57 |
| 3.3Data Collection .....                                                      | 60 |
| 3.3.1 Primary data collection (Fieldwork).....                                | 60 |
| 3.3.1.1 Consumer survey .....                                                 | 60 |
| 3.3.1.2 Retail sector questionnaire.....                                      | 61 |
| 3.3.1.3 Stakeholders visit and interview .....                                | 62 |
| 3.3.2 Secondary data collection (deskwork).....                               | 63 |
| 3.4 Phases of the research analysis .....                                     | 63 |
| 3.4.1 Survey Analysis .....                                                   | 63 |
| 3.4.2 Categorization analysis approach .....                                  | 64 |

|                                                                             |     |
|-----------------------------------------------------------------------------|-----|
| 3.4.2.1 Nine indicators for categorization FW .....                         | 65  |
| 3.4.2.2 Food Waste Management Decision Tree (FWMDT) .....                   | 67  |
| 3.4.3 Modelling and Simulation.....                                         | 68  |
| 3.4.3.1 PESTLE indicators.....                                              | 68  |
| 3.4.3.2 Fuzzy cognitive mapping (FCM).....                                  | 69  |
| 3.4.3.2.1 Concept Mapping Interface (pairwise comparison) step: .....       | 71  |
| 3.4.3.2.2 Matrix Interface step .....                                       | 72  |
| 3.4.3.2.3 Scenario Interface step .....                                     | 72  |
| 3.5 Chapter summary .....                                                   | 74  |
| CHAPTER 4: Results And Discussion .....                                     | 75  |
| 4.1. Introduction.....                                                      | 75  |
| 4.2. The research results.....                                              | 75  |
| 4.2.1 Food waste management awareness .....                                 | 75  |
| 4.2.1.1 Socio-demographic characteristics .....                             | 75  |
| 4.2.1.2 Awareness of the consequences and impacts of FW .....               | 77  |
| 4.2.1.3 Knowledge of the FWM .....                                          | 79  |
| 4.2.1.4 Food consumption behavior.....                                      | 81  |
| 4.2.2 Current Al-Khobar city FWM performance .....                          | 83  |
| 4.2.2.1 Retailers' survey results .....                                     | 83  |
| 4.2.2.2 Analysis of retailers' interviews .....                             | 89  |
| 4.2.3 Modelling and simulation analysis results .....                       | 91  |
| 4.2.3.1 Variables identification and causal relations of the model.....     | 92  |
| 4.2.3.2 Results of FCM .....                                                | 95  |
| 4.2.3.2.1 FCM of academia group .....                                       | 98  |
| 4.2.3.2.2 FCM of retailing group .....                                      | 104 |
| 4.2.3.2.3 FCM of government official group .....                            | 109 |
| 4.2.3.2.4 Community Map (CFCM) .....                                        | 111 |
| 4.2.3.3. FCM Dynamic analysis (scenario simulation).....                    | 113 |
| 4.2.3.3.1 Government policies scenario .....                                | 116 |
| 4.2.3.3.2 Green management scenario .....                                   | 116 |
| 4.3 Discussion.....                                                         | 119 |
| 4.3.1. Public Awareness, knowledge, and habit towards Sustainable FWM ..... | 119 |
| 4.3.2 FWMDT and the suggested sustainable FWM options .....                 | 124 |
| 4.3.3 Applicability of the FWMDT .....                                      | 128 |
| 4.3.4 Static and dynamic analysis of the model.....                         | 130 |

|                                                                     |        |
|---------------------------------------------------------------------|--------|
| 4.4 Chapter Summary .....                                           | 135    |
| CHAPTER 5: CONCLUSION AND RECOMMENDATION .....                      | 137    |
| 5.1 Introduction.....                                               | 137    |
| 5.2 Research conclusion.....                                        | 137    |
| 5.3 Research contributions.....                                     | 139    |
| 5.4 Recommendations.....                                            | 140    |
| 5.5 Research limitations.....                                       | 141    |
| 5.6 Future research.....                                            | 142    |
| 6. References .....                                                 | 144    |
| 7. Appendices.....                                                  | i      |
| Appendix 1: FWM consumer survey .....                               | i      |
| Appendix 2: FWM retailing sector questionnaire .....                | xvi    |
| Appendix 3: The nine indicators for categorization food waste. .... | xvii   |
| Appendix 4: FWMDT (part 1) .....                                    | xviii  |
| Appendix 5: FWMDT (part 2) .....                                    | xviii  |
| Appendix 6: Indications of mental model structural measurement..... | xx     |
| Appendix 7: The FCM of the Academia group in matrix form.....       | xxi    |
| Appendix 8: The FCM of the Academic expert 1 in matrix form.....    | xxii   |
| Appendix 9: The FCM of the Academic expert 2 in matrix form.....    | xxiii  |
| Appendix 10: The FCM of the Academic expert 3 in matrix.....        | xxiv   |
| Appendix 11: The FCM of the Academic expert 4 in matrix.....        | xxv    |
| Appendix 12: The FCM of the retail group in matrix for .....        | xxvi   |
| Appendix 13: The FCM of the retail expert 5 in matrix form.....     | xxvii  |
| Appendix 14: The FCM of the retail expert 6 in matrix form.....     | xxviii |
| Appendix 15: The FCM of the retail expert 7 in matrix form.....     | xxix   |
| Appendix 16: The FCM of the official expert 8 in matrix form .....  | xxx    |
| Appendix 17: The CFCM of Community in matrix form .....             | xxxi   |
| Appendix 18: Journal paper .....                                    | xxxii  |

## List of Tables

|                                                                                                                                           |     |
|-------------------------------------------------------------------------------------------------------------------------------------------|-----|
| Table( 1): Entities' responsibilities of food waste management in KSA. Source: Constructed by the author. ....                            | 21  |
| Table( 2): local initiatives for reducing food waste in KSA. Source: Constructed by the author.....                                       | 22  |
| Table ( 3): Causes of generation FW at the downstream FSC (the retail and consumer stages) in KSA. Source: Constructed by the author..... | 23  |
| Table( 4): Objectives aligned with research methods. ....                                                                                 | 73  |
| Table (5): The respondents' socio-demographic characteristics of the consumers' survey. ....                                              | 76  |
| Table( 6): Respondents' awareness regarding the FW impacts. ....                                                                          | 77  |
| Table (7): Respondents' knowledge regarding FWM.....                                                                                      | 79  |
| Table (8): Respondents classification upon their desirable FWM.....                                                                       | 81  |
| Table (9): Respondents' behavior regarding to food consumption.....                                                                       | 82  |
| Table (10): The current management of the three retailers for (Eatable waste) with the proposed alternative is based on the FWMDT.....    | 85  |
| Table (11): The current management of the three retailers for (Uneatable waste) with the proposed alternative is based on the FWMDT.....  | 87  |
| Table( 12): The key FWM factors in KSA via PESTLE category. Source: Constructed by the author.....                                        | 93  |
| Table (13): Stakeholders and participants for construction of fuzzy cognitive maps. Source: researcher's elaboration. ....                | 95  |
| Table (14): FCM network structure of individual cognitive maps for each stakeholder                                                       | 97  |
| Table (15): FCM network structure of stakeholder groups and social cognitive maps for KSA-FWM.....                                        | 97  |
| Table (16): Steady state (S.S) of model variables.....                                                                                    | 114 |
| Table (17): S.S and differences of model variables for both scenarios.....                                                                | 114 |

## List of Figures

|                                                                                                                                                                                                                                     |     |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|
| Figure 1: Household food waste estimate for each country. ....                                                                                                                                                                      | 4   |
| Figure 2: The schematic representation of main topics covered in this chapter. Source: Constructed by the author .....                                                                                                              | 10  |
| Figure 3: Food loss and waste Ratio for each product in the KSA. ....                                                                                                                                                               | 19  |
| Figure 4: Zero Hunger Hero Tips and Practices. Source: Constructed by the author..                                                                                                                                                  | 34  |
| Figure 5: The Food Waste Hierarchy adopted from.....                                                                                                                                                                                | 38  |
| Figure 6: Value added products obtained from food waste management. ....                                                                                                                                                            | 44  |
| Figure 7: The types of the methodologies adopted in this research. Source: Constructed by the author .....                                                                                                                          | 59  |
| Figure 8: Phases of the research methodology. Source: Constructed by the author .....                                                                                                                                               | 59  |
| Figure 9: Example of combining stakeholder maps. Source .....                                                                                                                                                                       | 70  |
| Figure 10: Operational framework of the FCM in this research elaborated by the research author. ....                                                                                                                                | 71  |
| Figure 11: The FCM of academia group of FWM, including all positive (blue) and negative (red) relationships between 19 variables. ....                                                                                              | 99  |
| Figure 12: Results of the network analysis for FCM of academia group .....                                                                                                                                                          | 99  |
| Figure 13 (a,b,c,d): individual FCMs collected from 4 academic members.....                                                                                                                                                         | 101 |
| Figure 14: Results of the network analysis for FCM of academic members (part 1).                                                                                                                                                    | 102 |
| Figure 15: Results of the network analysis for FCM of academic members (part 2).                                                                                                                                                    | 103 |
| Figure 16: The FCM of retail sector group of FWM .....                                                                                                                                                                              | 105 |
| Figure 17: Results of the network analysis for FCM of retail group .....                                                                                                                                                            | 105 |
| Figure 18 (a,b,c): Individual FCMs collected from 3 retail members .....                                                                                                                                                            | 106 |
| Figure 19(a, b, c): Results of the network analysis for FCM of retail members .....                                                                                                                                                 | 108 |
| Figure 20: The FCM of official group of FWM .....                                                                                                                                                                                   | 110 |
| Figure 21: Results of the network analysis for FCM of official group.....                                                                                                                                                           | 110 |
| Figure 22: The Community Map (CFCM).....                                                                                                                                                                                            | 112 |
| Figure 23: Results of the network analysis for CFCM .....                                                                                                                                                                           | 112 |
| Figure 24: Relative strength of factors under government policy scenario values that relative change from the steady state and the results of increasing maximum only one factor the government policy and not across factors. .... | 117 |
| Figure 25: Relative strength of factors under green management scenario values that relative change from the steady state and the results of increasing maximum only one factor the green management and not across factors. ....   | 118 |
| Figure 26: An integrated approach for increasing awareness of FWM .....                                                                                                                                                             | 124 |

# **CHAPTER 1 Introduction Of The Study**

## **1.1. Introduction**

Food waste (FW) represents a substantial concern with far-reaching implications for the environment, economy, society, and public health. It presents a multifaceted and intricate problem, characterized by challenges in identifying its root causes and understanding its wide-ranging effects (Närvänen, 2019). As food is wasted, so is the energy and water invested in its production, exacerbating environmental strain. Not only this, when discarded in landfills, food waste generates methane emissions, a potent greenhouse gas exceeding even carbon dioxide levels(WWF, 2016).

According to the Food and Agriculture Organization (FAO), over 850 million people worldwide struggle to access sufficient food. Despite this, an estimated 1.3 billion tons of food are wasted annually, resulting in a staggering economic loss of approximately USD 900 billion globally. Food waste and loss occur throughout the entire food supply chain (FSC), from the farm to the consumer's plate. These losses can occur at various stages, including post-harvest handling, transportation, storage, and distribution, and can vary depending on factors such as location, available infrastructure, and management practices (Baig, Al-Zahrani, Schneider, Straquadine, & Mourad, 2018; FAO., 2011).

Many developed countries e.g. Germany, Italy, U.S, and Japan have more than 40% of food wastage at the retail and consumption stages, a volume sufficient to cover global hunger three time over. Conversely, in developing countries, the majority of food waste occurs during post-harvest and processing stages, primarily due to limited resources and

infrastructure(Huang, 2020; Xue, 2017). In 2007, food waste was estimated at 11.6 million tons, which was reduced to 10 million tons in 2015 due to social awareness to prevent FW. However, FW is estimated to increase by 0.2 to 2.0 million tons per year by 2025, implying that recent regulations and policies are insufficient or impractical to reduce FW to achieve food security and sustainable development(FAO., 2017).

According to the National Transformation Program, the downstream of the food supply chain, which includes households, retail, and food service sectors, is the primary source of food waste generation in the Kingdom of Saudi Arabia (KSA)(UNEP, 2021). In KSA in 2020, wasted food accounted for 33% of the total food production, resulting in an annual cost of approximately USD 150 billion. A significant portion of this waste, comprising 0.917 million, 0.608 million, and 0.557 million tons annually, stems from flour and bread, fruits, and rice wastage, respectively(Mu'azu, 2019; Saudi Grains Organization, 2019).

According to the Food Waste Index report, the average per capita annual food wastage in Saudi Arabia in 2021 was estimated at 105 kg **Figure 1**(UNEP, 2021). Recent studies in KSA revealed that the total quantity of Municipal Solid Waste (MSW) produced in 2014, which was estimated to be 15 million tons, is forecasted to be doubled by 2033. Moreover, half of MSW component is organic waste having the largest contribution of nearby 50.6% (Mu'azu, 2019). Interestingly, three main Saudi cities including Riyadh, Jeddah and Dammam generate 40% of the total MSW(Bashraheel, 2020). FW has a profound and detrimental impact on the environment, primarily through the inefficient utilization of natural resources such as land, energy, and water during food production (Grizzetti, 2013). As highlighted by Mu'azu et al., 2019 and Al-Khateeb et al., 2021, several FW-related issues persist in KSA. These include cultural norms and doctrines that

endorse extravagant festivals, resulting in an elevated incidence of wasted food beyond the average level. Additionally, challenges related to the handling, management, and formulation of FW-related policies further exacerbate the situation. In light of the prevailing environmental conditions and challenges within the Kingdom and the Gulf Cooperation Council (GCC) region, including desertification, arid climates, water scarcity, and limited soil fertility, there exists a compounding risk to food security (Al-Khateeb, Hussain, Lange, Almutari, & Schneider, 2021; Mu'azu, 2019).

Therefore, KSA (Al Khobar City) food stakeholders need a better understanding of the short- and long-term outcomes associated with their unsustainable food waste management (FWM) in addition to identifying knowledge gaps in FWM concepts, factors, and methods. Subsequently, improving and implementing new management practices and holistic approaches to the field, FWM should be encouraged to achieve sustainability.

The issue of FW has garnered increasing attention in recent times, prompting the development of novel approaches and methodologies. Nevertheless, a consensus remains elusive regarding the precise definition of FW and the categorization of its diverse manifestations, including strategies for optimal and sustainable management. The research problem, questions, and structure are described. In addition, the research aim, and objectives are established, and the research definition of terms is defined.

| M49 code <sup>1</sup> | Country              | Household food waste estimate (kg/capita/year) | Household food waste estimate (tonnes/year) | Confidence in estimate |
|-----------------------|----------------------|------------------------------------------------|---------------------------------------------|------------------------|
| 51                    | Armenia              | 93                                             | 275 195                                     | Low confidence         |
| 31                    | Azerbaijan           | 93                                             | 934 872                                     | Low confidence         |
| 48                    | Bahrain              | 132                                            | 216 161                                     | Medium confidence      |
| 196                   | Cyprus               | 95                                             | 113 312                                     | Low confidence         |
| 268                   | Georgia              | 101                                            | 403 573                                     | Medium confidence      |
| 368                   | Iraq                 | 120                                            | 4 734 434                                   | Medium confidence      |
| 376                   | Israel               | 100                                            | 848 395                                     | Medium confidence      |
| 400                   | Jordan               | 93                                             | 939 897                                     | Low confidence         |
| 414                   | Kuwait               | 95                                             | 397 727                                     | Low confidence         |
| 422                   | Lebanon              | 105                                            | 717 491                                     | Medium confidence      |
| 512                   | Oman                 | 95                                             | 470 322                                     | Low confidence         |
| 634                   | Qatar                | 95                                             | 267 739                                     | Low confidence         |
| 682                   | Saudi Arabia         | 105                                            | 3 594 080                                   | High confidence        |
| 275                   | State of Palestine   | 101                                            | 501 602                                     | Low confidence         |
| 760                   | Syrian Arab Republic | 104                                            | 1 771 842                                   | Low confidence         |
| 792                   | Turkey               | 93                                             | 7 762 575                                   | Low confidence         |
| 784                   | United Arab Emirates | 95                                             | 923 675                                     | Low confidence         |
| 887                   | Yemen                | 104                                            | 3 026 946                                   | Very low confidence    |

Figure 1: Household food waste estimate for each country (UNEP, 2021).

## 1.2. Research Problem

FW entails environmental, ethical, and economic impacts. FW contributes to excess consumption of natural resources, which along with greenhouse gas emissions such as carbon dioxide, methane, nitrous oxide, and fluorinated gases from decomposing food, impact global climate change (Hall, 2009; Isah, 2020). There is a broad agreement on the urgency of reducing the current FW, which requires everyone's involvement along the food supply chain, including policy makers, food producers and retailers as well as food consumers. Moreover, FW management represents a potential opportunity to enhance both food security and environmental sustainability (S. Wang, Wang, J., Zhao, S., & Yang, S., 2019). Consequently, it is critical to support policy makers in the development of strategies and policies for maximizing the effectiveness of food waste management practices in the country through structured assessment and better-informed selection of food waste management methodologies for meet sustainability goals (Costa, Massard, & Agarwal, 2010; Garcia-Garcia, Woolley, & Rahimifard, 2015). With limited arable land and insufficient water resources, the Kingdom of Saudi Arabia (KSA) relies on large-scale imports

and food subsidies to meet its food needs (Haque, 2022). Therefore, food waste is a major issue for sustainable management in Saudi Arabia. The key issue is the adequate and sustainable food waste management in the stakeholders at the end of FSC (retail sector) is not possible due to the inability of the local government of the King of Saudi Arabia to provide an adequate regulatory framework and programs related to FWM. This research study is addressed the changes that might influence the FWM, the roles of the stakeholder interactions, as well as to explore potential management to prevent and reduce the current food waste generation. This study aims to investigate the performance of the retail sector in Khobar City, Saudi Arabia. Hypothetically analyzing current FWM and providing suggested scenarios that will support food stakeholders in applying FWM for sustainable solutions.

### **1.3. Research Questions**

The key question proposed by this research study is: Is there sustainable food waste management in Saudi Arabia? To address this question, there are other questions should be asked:

1. Is there sufficient social awareness related to FWM?
2. Are there any challenges or potential limitations associated with FWM?
3. How does the food retail sector handle and manage FW?
4. What are the changes in current food management practices might lead to the sustainability and reduction in food waste in Saudi Arabia?

### **1.4. Research Aim and Objectives**

The aim of this research is investigating food waste management practices in KSA, Al Khobar city, as well as explaining the factors influencing the

FWM at different stakeholders (academia, retail, officials, and consumer) to improve FWM performance, and achieve sustainability in the field. To achieve this goal, the following objectives have been identified and studied:

1. To estimate the public awareness about food waste management.
2. To provide suggestions and guidelines for implementing recommendations in the future.
3. To analyze Saudi's stake-holders sustainable FWM implementation's limits and barriers.
4. To minimize environmental impacts of FW by using innovative management practices.
5. To explore stakeholders' perspectives and the role inter-actions in regard of FWM in the Saudi Arabia (Al Khobar city).

## **1.5. Research Scope and Significance**

The research provides an in depth understanding the current public knowledge, and attitudes towards food waste management. It provides an opportunity for the FWM system to propose an integrated approach (environmental education, policy and technology) to change common unsustainable practices.

The research creates an opportunity to address the knowledge gaps between the stakeholders' perspective for identifying the problems that need to be cover the gap and changes that can be made. It sets up various scenarios to explore the key variables that influence the FWM in the Al Khobar city, in order to set up regulatory constraints for the managing FW.

The research study is significant and has practical benefits. The research methodologies provide FW classification to the different type of food that

get wasted in the retailers and designing the most sustainable solution for FWM. FWM alternatives have been analyzed in detail in the FWM framework: redistribution, animal feeding, anaerobic digestion, composting, and thermal treatments with energy recovery. Furthermore, some procedures have been previously adopted and implemented in other countries due to their experience with sustainable FWM. There is also a need to apply them in our region to ensure the study give us the best possible experience and to understand the impact and the weakness of the existing FWM performance in area. The research study has innovated in management practices in an attempt to move towards sustainable development.

## **1.6. Structure Of This Research**

The research is divided into five chapters and a series of appendices which are structured as follows:

### **Chapter 1: Introduction**

It provides an introduction, and the overview to food waste management. It also presents of the problem, questions, aim, objectives, and significance of the research.

### **Chapter 2: Literature Review**

In this chapter, it exposes the findings and acknowledges of the previous related work on the topic of food waste management in the field.

The key domain of this chapter shows the variety of food waste management practices globally, and the preferable approach and management has been implemented that has less negative environmental impact and support achieving the sustainable development in the field. A controversy definition of the food wastage, food waste in Saudi Arabia challenges and solutions, and the strategies to curb food waste all these have been reported in the literature review.

### Chapter 3: Methodology and Procedures

It presents the selection of methodologies and procedures that have been adopted and followed in this study. The methodological approach outlines into data collection, phases of the research analysis, and modelling and simulation.

### Chapter 4: Findings and Discussion

The chapter displays the results and discussion of the study and compare them within the context of literatures. This chapter highlights and evaluates different case studies of the retail industry in Khobar city, Saudi Arabia.

### Chapter 5: Conclusion and Recommendations

It includes the final overall summary and conclusion. It significantly evaluates the situation of the study and makes recommendations for further research. It also provides innovative FWM practices to achieve sustainable FWM in the country (KSA).

## **1.7. Chapter Summary**

This chapter presents the research overview and background, including the questions, objectives and significances identified for this paper. The research structure and terminology are defined. The next chapter reviews the literatures related to FWM, as well as the most common alternative tools and methods for managing FW that contribute to sustainable FWM.

## **CHAPTER 2 Literature Review and Previous Studies**

### **2.1 Introduction**

This chapter provides the literature review and previous work in the food waste management. It reveals the past and present development of the research topic. It highlights a controversial definition that food wastage is generally into three terms food surplus, waste, and loss with their classification. However, food waste in (retail stage) is the main definition of this research study. It provides a review of the current FWM in Saudi Arabia. It also describes the adverse environmental influences of food waste and provides a serious review of studies addressing the relationship between strategies and application of food waste management. In addition, it's exploring the existing methods, alternatives, and practices that might help achieve sustainable development in the research area. The main topics covered in this chapter is represented in (Fig 2). The chapter concludes with a summary of previous work, and further benefits are considered in this study.

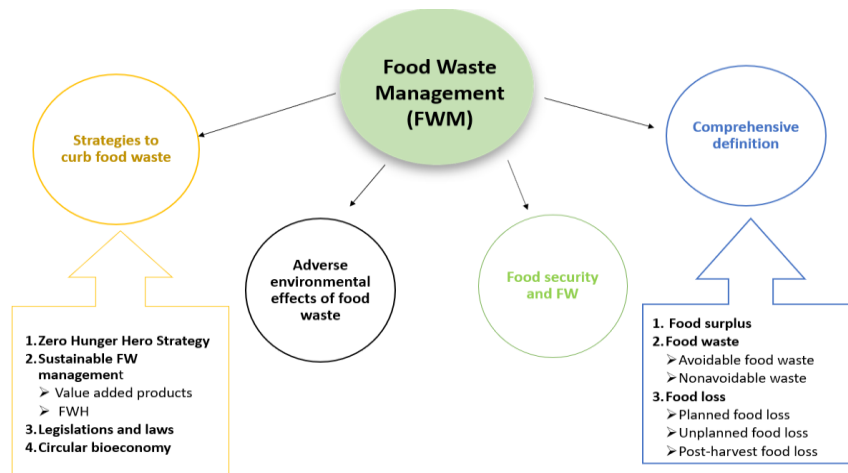


Figure 2: The schematic representation of main topics covered in this chapter. Source: Constructed by the author

## 2.2 Defining food wastage, a contentious issue

The precise food waste (FW) terminology has been a subject of controversy, with inadequate consideration until the recent report (Teigiserova, 2020). Ambiguities in food waste terminology contribute to variations in its management across countries, posing challenges for the systematic comparison of research results (Huang, 2020). Due to this, managing food waste sustainably proves to be challenging. The aforementioned reports provide in-depth understanding, presenting six categories of food waste: including naturally inedible, edible, industrial residue, inedible owing to managing ineffectively, inedible owing to any natural cause, and the one not taken into consideration for (Teigiserova, 2020). The categorization with respect to wastage facilitates straightforward analysis to enhance and examine waste management practices. On a worldwide scale, there exists a significant gap in the definitions and sorting of terms such as food waste, loss, surplus, resulting in the waste or loss of over 50% of the food prior to or after human consumption. Food loss has been defined by Food and Agriculture Organization (FAO) as “any deduction in the amount of food in the food supply chain.” However, any kind of food loss cannot be regarded

as food waste; the term refers to food which was meant to be consumed by human beings but could not be consumed. The transition from food loss to waste is not always clear (FAO., 2014; Isah, 2020; Kibler, 2018). The subsequent section delineates the various terminologies associated with the generation of food wastage. Three primary terms related to the Food Supply Chain (FSC) have been identified, including food surplus, food waste which includes both the avoidable and non-avoidable waste, and the third term is food loss which includes planned, unplanned, and post-harvest as described below in detail and (Fig 2).

### **2.2.1 Food surplus**

Food surplus refers to the excess amount of food produced or made available beyond the demands and needs of the population. This surplus is a result of overproduction in agriculture, including additional quantities of imported agricultural products facilitated by government organizations. The surplus encompasses the food that is inedible food that is left even before meeting suppliers, is post-harvest and having an oversupply, falling into this category. Food production is subject to change due to factors including ecological and economic influences, impacting crop choices by farmers in response to market prices.

While food surplus can fluctuate yearly, it is important in offsetting food deficits while taking into account overall food security. Achieving security is commendable and can bring economic benefits as well as support humanitarian efforts through food aid. Despite its positive implications, “food surplus” is often misunderstood and is mixed with “food waste.” In reality, food surplus offers a sustainable approach to managing food waste and acts as a detriment against potential food shortages (Atkins & Bowler, 2016; Huang, 2020).

It is essential to note that food surplus is a global environmental concern that doesn't entirely eliminate scarcity. The ongoing discussion in food waste literature revolves around two key gaps: the disparity between producing food and consuming it and the overall current presence of food versus its estimated needs by 2050. A comparison of per-capita food with market-level food presence indicates that some developed countries, including the United States and certain European Union (EU) nations, experience a food surplus exceeding one thousand kilocalories per capita (Papargyropoulou, 2014).

### **2.2.2 Food waste**

As per FAO, FW means all the food which could be consumed but is discarded during retail and consumption stages, typically happening at the downstream side of food supply chain (FSC) (Al-Khateeb et al., 2021; Garcia-Garcia et al., 2015; Kibler, 2018). This waste can be intentional, influenced by public behaviors and beliefs, leading to scenarios such as excessive food purchases by restaurants, retailers acquiring surplus produce for promotions, the preparation of large meals for hospitality events, disposal of expired food perceived as inedible, and discarding low-demand grocery items (Huang, 2020; Papargyropoulou, 2014).

As per the Food Use for Social Innovation by Optimizing Waste Prevention Strategies (FUSIONS) FW encompasses wasted food which also encompass the parts which are non-edible, extending definitions for a better understanding (Garcia-Garcia et al., 2015). Due to disparities in definitions and considerations, food waste is categorized into two types: avoidable and non-avoidable food waste. This classification aids in identifying areas which could be improved to avoid waste which is preventable and devising strategies for waste reduction in a more sustainable way (Papargyropoulou, 2014).

### **2.2.2.1 Avoidable FWs**

Avoidable food waste, according to WRAP, pertains to edible food discarded due to exceeding needs, leftovers, lack of consumer appeal, or inedibility caused by putrefaction. Practices based on cultural, religious, or individual beliefs, such as traditional customs, also contribute to this domain (GOV.UK., 2017; Papargyropoulou, 2014). In upscale markets, where food presentation is carefully managed, misshapen fruits and vegetables may be wasted despite their nutritional value or remaining expiration time (Science, 2021). Among the restaurant and food delivering industry, food waste can be avoided occur in plate waste as well as in the kitchen and in-between. Examples include buffet leftovers, burned food, spilled food and water, overstocking, and inefficient meal preparation methods (Martin-Rios, 2018).

### **2.2.2.2 Nonavoidable FWs**

Components of food typically deemed inedible in food services, encompassing activities including cooking, packaging, and storage. This category is inclusive of nonvoidable food waste generated both at the front office, encompassing dish waste as fruit skins and meat bones, or at back-office like packaging issues and instrument malfunctions (Bernstad Saraiva Schott, Vukicevic, Bohn, & Andersson, 2013; GOV.UK., 2017; Papargyropoulou, 2014).

### **2.2.3 Food Losses (FLs)**

Food loss pertains to food that is edible that undergoes spoilage or gets wasted in the initial phases of food supply chain, as per FAO (Al-Khateeb et al., 2021; FAO., 2011; Garcia-Garcia et al., 2015). This spoilage occurs during post-harvest handling or transportation in agricultural processing, rendering the food unsuitable for marketing due to pest infection or issues

in storage methods (Huang, 2020). Occurrence of FLs entails that there is a dire need for lavish infrastructure investments in this field (Papargyropoulou, 2014).

According to FAO, FLs are applicable to food intended for consumption of humans, excluding inedible parts suitable for animal feed (Papargyropoulou, 2014). Consequently, food initially designated for human consumption unintentionally becomes inedible for humans, leading to inedible loss which could be termed as planned and unplanned, depending on destination for the food outside the food chain (FC) of humans. Several elements including the ecological and market factors, such as fluctuations in the seasons, agricultural weeds or pests invasion, diseases to animals, market shortages, and price increases, differentiate between planned and unplanned losses (Garcia-Garcia et al., 2015; Spang, 2019).

It can contribute to environmental sustainability when local authorities valorize and manage them intelligently, utilizing methods such as conversion by bio-based methods and bacteria digestion, to convert losses and waste into various types of useful products including biofuels. Such kind of innovative conversion ideas are particularly important for the countries with limited resources helping them to cater for the high costs of the electricity in their troubled industries making use of the feedstock. Additionally, the converted products can be used as for several other applications including compost or feed for animals (FAO., 2011; Spang, 2019).

Fatty substances and lignocellulosic components from food represent sources of valuable items for refinery. The integration of renewable practices with Food Loss & Waste valorization concepts facilitates production regarding substances from living biomass employing environmentally benign industrial oriented processes. Green chemistry offers significant

benefits related to climate safety, health of the individuals, as well as efficiency in energy consumption. The benefits include prevention of loss, the use of innovative chemicals related to climate reducing reliance on reagents made by human which are harsh, that facilitate biodegradability, utilization of renewable materials, and prevention attempts at pollution.

Various feedstocks can be employed for biofuel production based on the desired type of biofuel. Brazil stands as second-largest producer of bioethanol globally, and the stability of its market, coupled with the utilization of ethanol fuel in all vehicles, eliminates the need for oil imports. Traditional bioethanol and biodiesel plant-based exhibit many drawbacks that renewable biofuels tackle. Projections suggest that greater than thirty percent of consumption worldwide would be realized with biofuels that are renewable by the mid of this century, with biomass-based biodiesel production reaching 21,463 million liters annually. The appropriateness of such conversion is supported by characteristics such as a higher ratio of hydrogen as compared to carbon, high saturation phenomenon of bonds, and lesser solubility in water. There are several other benefits including an enhancement in octane number, contributing to the reduction of sulfur oxides, nitrogen oxides, and particulate emissions, thereby minimizing air pollution (Isah, 2020).

#### **2.2.3.1 Planned FL**

When food loss intentionally sets in during the upstream part, it falls under this category (FAO., 2011; Spang, 2019). The intention is repurposing the food to alternative uses including animal feed or insect consumption, particularly by some special type of larvae. One study comparing 4 disposal methods related to food loss found that 2 techniques involving the use of wet and dry pig feed in South Korea, serving as animal feeding styles, had better results with lower environmental and health impacts compared to

previously employed techniques in the United Kingdom (Salemdeeb, 2017). Planned loss can contribute to addressing food quality and safety concerns and mitigating the issue of diseases solely attributed to food including infections (Guillard, 2018; Science, 2021). On a worldwide scale, lessening the climatic impacts and reducing reliance on fossil fuels in packaging, while conserving world resources, points to essential goals for achieving sustainable food consumption. To mitigate the environmental footprint of food production and distribution, emphasis is placed on supporting local and seasonal produce to diminish transportation-related greenhouse gas emissions. Additionally, sustainable agriculture practices, including organic farming and agroecology, play a vital role in preserving soil health and reducing the use of synthetic inputs that contribute to climate change.

#### **2.2.3.2 Unplanned FL**

Unplanned food loss is due to unintentional causes during the upstream process owing to inadequate storage techniques, insufficient cooling facilities, defects in fridge trucks, or during long-distance transportation. Addressing unplanned loss can be achieved by shortening the food processing chain and promoting farming (Science, 2021; Spang, 2019). With over half of individuals residing in downtown areas where production and further treatment of food predominantly happen in village sites, urban farming becomes crucial. Rural farms, while supplying food for a large population, also can get the food easily, which is restricted to downtown areas. Farming in urban areas in cities reduces dependence on supply chains which are distant and prevents the use of fuels in the process of transporting, packaging etc. (Science, 2021). This approach ensures healthier living for urban populations benefiting from fresh food. Establishing places for processing

fresh food stock in urban areas becomes imperative to bypass long transportation and associated challenges.

### **2.2.3.3 Food loss during post-harvest**

Loss of food can occur in this stage as well, representing both loss in quality as well as quantity during the production time, spanning handling, storing, and packing phases (FAO., 2011). Post-harvest loss of food is approximately 2,600 kcal per capita per day, encompassing animal as well as household waste (Papargyropoulou, 2014). Numerous factors during harvest of raw materials contribute to post-harvest loss, commonly including problems in techniques for drying processes and storing issues, the use of below-par packaging materials, and insufficient transport facilities. Harvesting techniques, whether mechanical or hand-picked, can also impact the extent of losses. Delayed harvesting exposes food items to undesirable ecological conditions and pests, resulting in a significant amount of food being lost.

Low-income countries are more prone to higher levels of post-harvest losses compared to developed countries, in which losses often occur at the retail and later stages estimated at over 20% of food loss. Developed countries commonly employ mechanical harvesting for different commodities, whereas handpicking remains a prevalent technique in less-developed countries, relying on labor-intensive efforts that may prolong harvesting periods and increase losses. Scarcity of any financial incentives and investment in drying systems related to agriculture and industry is main contributor to food loss in developing countries, in contrast to advanced countries that boast advanced equipment in their food systems, including automated devices for food production, irrigation, and storing and packing. These disparities between these two kinds of countries provide valuable information into losses pertaining to post-harvest (Spang, 2019). Additionally, FW

contributes to 50% of the total municipal waste, highlighting the significant impact of wastage on overall waste management systems.

### **2.3 Previous studies-FWs in Saudi Arabia (KSA) challenges and solutions**

Saudi Arabia faces a substantial challenge in food waste, with a staggering 105 kg per capita per year, making it a global leader in food waste, even surpassing industrialized countries (Baig, Al-Zahrani, et al., 2018). Survey data from 1135 restaurant consumers shows that 1/3<sup>rd</sup> of imported food is lost due to reduced shelf-life as well as owing to the warm environmental conditions prevalent in that area (Baig et al., 2022). The total FLW rate is 33.1%, while the food waste rate is 18.9%. (2,325 million tons) with a total value equivalent to 40.480 million SR/year. Rice (31%), bread and flour (25%), and meat (19%) are the products with the highest proportion of waste, as they are common meals at all supply chain sites in Saudi Arabia in (Fig 3) (Alshabanat et al., 2021).

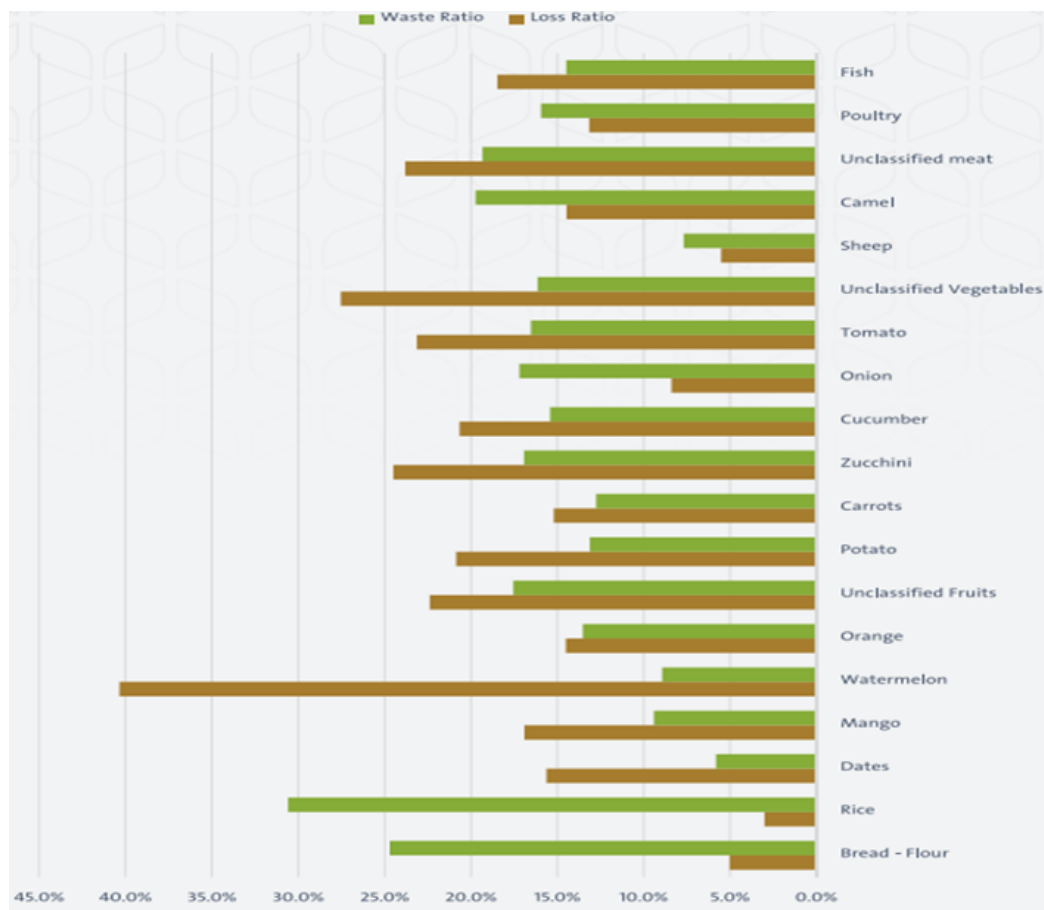


Figure 3: Food loss and waste Ratio for each product in the KSA (Saudi Grains Organization, 2019).

The situation of food waste management (FWM) in the kingdom similar to the situation in GCC countries and other under-developed countries. So far, there is no clear and significant regulations or operational guidelines in FWM in KSA (Al-Khateeb et al., 2021). Currently, in KSA, solid waste management (SWM) legislation is either scarce or not well established, and education programs are insufficient to develop FW collection and separation, and there is a lack of encouragement for FW recycling for useful activities. Consequently, FW is blended with other municipal solid waste without segregation. However, there is very few municipalities have paid attention to FWM whereas draft legislations are incomplete, which now seems to be not permitted and as such cannot be implemented (Al-Khateeb et al., 2021). In addition, no state strategy for adopting better sustainable

management practices, so throw in landfills as common management practice. Despite this, KSA's food waste recycling operations have started slightly, most of which are carried out for beneficial purposes and account for only a small part of the total FW generated by informal activities (Mu'azu, 2019).

The Kingdom's Vision 2030 incorporates a magnificent plan for the future of the Kingdom. It aims to protect the environment and improve waste management through the concept of a circular economy instead of using the liner economy (SA, 2023). Accordingly, there are different entities as shown in (Table 1). The list of roles and responsibilities for each agencies is based on the following sources: (Aldhafeeri & Alhazmi, 2022; Alshuwaikhat & Mohammed, 2017; Baig, Gorski-Steiner, & Neff, 2018; Haider, 2022; Hussein, 2022; MEWA, 2016; MRAH, 2019; Muhammad, 2019; MWAN, 2019; Saudi Grains Organization, 2019; SIRC, 2017; Zafar, 2023).

Saudi Arabia has launched some local initiatives for reducing food waste as shown in Table 2 with following references:(Fareed, 2017; Hussein, 2022; Muhammad, 2019; SA, 2016, 2023; Saudi Grains Organization, 2019; Savola., 2019). Despite the Saudi's initiatives that mentioned above, The Kingdom's influence on FWM, which is still in its infancy, requires further efforts to address the gaps in FW management. For example, FWM in Saudi Arabia faces many challenges. For example, the public response to FW reflects a lack of knowledge and understanding of the importance of recycling and reusing FW at the individual and state levels. It is also important to shape individual norms and cultural trends in food consumption. There are many causes of FW in all food supply chains in both developed and developing countries (Canali et al., 2017; Y. Wang, Yuan, Z., & Tang, Y., 2021). Reasons for FW in retail and household phases in Saudi Arabia

are listed in the Table 3 and based on the following references: (Al-Khateeb et al., 2021; Baig, Gorski-Steiner, et al., 2018; Barilla, 2012; El Bilali & Ben Hassen, 2020; Elshaer, Sobaih, Alyahya, & Abu Elnasr, 2021; FAO., 2011; Flanagan, Robertson, & Hanson, 2019; GEO6, 2019; Hoover, 2017; Mu'azu, 2019; UNEP, 2021; Y. Wang, Yuan, Z., & Tang, Y., 2021; WWF, 2016).

Table( 1): Entities' responsibilities of food waste management in KSA. Source: Constructed by the author.

|          | <b>Organisational Entities</b>                                   | <b>Responsibilities</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | <b>Role</b>        |
|----------|------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------|
| <b>1</b> | The Ministry of Environment, Water and Agriculture (MEWA) (2016) | <ul style="list-style-type: none"> <li>• Develop plans, policies, laws and initiatives to reduce food waste and achieve sustainable development.</li> <li>• Establishment of an environmental agency.</li> <li>• Environmental governance, investment, and funds for environmental projects.</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                               | Policy maker       |
| <b>2</b> | National Center for Waste Management (MWAN) (2019)               | <ul style="list-style-type: none"> <li>• Regulate and monitor waste management performance and support investment through circular economy concepts for waste management to achieve sustainable development goals.</li> <li>• Establish proper management practices and modern technologies.</li> <li>• Increase recycling activities to 42% by 2035.</li> <li>• Total diversion rate from landfills to 82% by 2035.</li> <li>• Waste-to-compost to 35% by 2035.</li> <li>• Waste-to-energy in small scale to 19% by 2035.</li> <li>• Encourage research and innovations in the field of integrated waste management and cooperation with universities, research centers and institutions.</li> </ul> | Official regulator |
| <b>3</b> | General Food Security Authority (GFSA) (2023)                    | <ul style="list-style-type: none"> <li>• Suggest laws, strategies and regulations related to food security.</li> <li>• Manage and organize work related to food security with relevant agencies.</li> <li>• Provide proper partnerships and investment with private food sector.</li> <li>• It aims to reduce the FW rates to 50% by 2030 to meet SDG (12.3).</li> </ul>                                                                                                                                                                                                                                                                                                                              | Official Regulator |

|   |                                                      |                                                                                                                                 |                                                         |
|---|------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------|
| 4 | The Ministry of Municipal and Rural Affairs (1975)   | <ul style="list-style-type: none"> <li>Collect, transfer, and discard the solid waste</li> </ul>                                | Waste collection and disposal authority                 |
| 5 | The Saudi Investment Recycling Company (SIRC) (2017) | <ul style="list-style-type: none"> <li>Operate and invest in all waste types in recycling activities in the Kingdom.</li> </ul> | Waste recovery and recycling authority (private sector) |

Table( 2): local initiatives for reducing food waste in KSA. Source: Constructed by the author.

|   | Initiatives                         | Activities                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|---|-------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1 | Food bank (Eta'am) (2012)           | <ul style="list-style-type: none"> <li>It aims to collect leftovers and distribute them to those in need.</li> <li>In 2019, it saved 1,975,000 meals and served 20,000 people.</li> <li>It operates in five Saudi's cities (Dammam, Jubail, Al-Ahsa, Jeddah and Riyadh).</li> <li>It had worked with 26 hotels, 42 restaurants, 466 wedding parties, and 13 companies.</li> <li>It helps to raise social awareness about saving and sharing food.</li> </ul> |
| 2 | The Saudi Grain Organization (2016) | <ul style="list-style-type: none"> <li>Inaugurate the Food Loss and Waste Index in the Kingdom (2019) (baseline) is the first outcome of a national program to reduce food loss and waste.</li> <li>Expand the grains storage capacity and enhance the storage conditions to preserve them for longer time.</li> </ul>                                                                                                                                       |
| 3 | The Kingdom's Vision 2030 (2016)    | <ul style="list-style-type: none"> <li>It is the start point of the Saudi's initiatives for achieving sustainable development goals.</li> <li>Although it does not deeply focus into FW, the vision ensures investments in solid waste management and provide a program for food suppliers to reduce their waste.</li> </ul>                                                                                                                                 |
| 4 | Negaderha program (2017)            | <ul style="list-style-type: none"> <li>It is a food business initiated by the private sector (Savola Group) as food business.</li> <li>It has alliance with the UNEP, WRAP, and NPOs for managing food waste.</li> <li>providing 1 million containers for saving leftovers.</li> <li>Improving food business' guide on food waste reduction.</li> <li>initiating public awareness campaigns.</li> </ul>                                                      |
| 5 | Edama (2017)                        | <ul style="list-style-type: none"> <li>It is King Abdullah University of Science and Technology (KAUST) initiative for organic waste recycling solutions.</li> <li>Transforming organic waste into resources for desert agriculture.</li> </ul>                                                                                                                                                                                                              |

|  |  |                                                                                                                       |
|--|--|-----------------------------------------------------------------------------------------------------------------------|
|  |  | <ul style="list-style-type: none"> <li>• Producing desert compost to increase the fertility of sandy soils</li> </ul> |
|--|--|-----------------------------------------------------------------------------------------------------------------------|

Table ( 3): Causes of generation FW at the downstream FSC (the retail and consumer stages) in KSA. Source: Constructed by the author

| Retail stage                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | Consumer stage                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none"> <li>• Inadequate governmental policies and frameworks.</li> <li>• There is no classification and isolation strategy.</li> <li>• Inadequate inventory Management at retail level.</li> <li>• Improper food storage, packaging and transportation the food.</li> <li>• Lack of staff training on stacking and shelving rotation.</li> <li>• Demand for large quantities of foods due to poor forecast management</li> <li>• Aesthetic standards in food shapes, sizes, and physical blemishes to meet consumer preferences</li> </ul> | <ul style="list-style-type: none"> <li>• Technology <ul style="list-style-type: none"> <li>▪ Online food application.</li> </ul> </li> <li>• Economic development: <ul style="list-style-type: none"> <li>▪ Income generation.</li> <li>▪ Food costs/ availability and affordability of food.</li> </ul> </li> <li>• Social factors: <ul style="list-style-type: none"> <li>▪ Lack of public awareness (retailer offers, not use shopping list, spoilt and passed expiry date, lack knowledge of how to manage leftovers, inadequate storage of food, and misunderstanding between use by and best before)</li> <li>▪ Population growth (the number of the family's members)</li> <li>▪ Cultural and religious factors (special occasions, Ramadan, and Alhajj)</li> </ul> </li> </ul> |

Computer-based studies on 2454 respondents emphasize the need for individual awareness, improved food safety, effective food management of food waste, and regulatory adjustments to reduce waste and transform into valuable items (Althumiri et al., 2021). Various things contribute to high levels of waste in the vicinity, including but not limited to, societal and religious influences, stringent laws, and the involvement of stakeholders, necessitating a scientific exploration of these aspects (Elshaer et al., 2021). Significant amounts of food are discarded to accommodate new groceries, with importing companies without awareness, and planning inadequately, with extra food being supplied during meetings and gatherings. Converting

discarded food into compost could potentially contribute around \$70 million to state's exchequer (M. Waqas, Nizami, A. S., Aburiazaiza, A. S., Barakat, M. A., Rashid, M. I., & Ismail, I. M. I., 2018).

There have not been enough studies related to Africa and Saudi Arabia related to food waste, posing potential challenges to food safety and sovereignty in the future (Oelofse, 2020). Regarding 2012, the potential for production employing food waste was estimated at 990.40 megawatt (MW/year), with predictions indicating it could reach 2196.76 MW by 2025 through refuse-derived fuel (RDF) and incineration scenarios (Ouda, 2016). An investigation in 2015 reported that the country's food waste constituted 50.6% equaling to 7.7 Mt/year. Implicitly, Saudi Arabia could produce electricity of 2.99 Terawatt (TW) with the help of anaerobic digestion (AD) from the FW (Nizami, 2015).

An initial investigation on biofuel production suggests Saudi population, including pilgrims, can generate 1.08-1.41 M ton biodiesel by 2030, contributing significantly to the economy of the country. However, the economic boost relies on diverting waste from landfills to technological processing, with potential challenges in the acquiring of waste, its separation, reactor model design, and attributes of the obtained biodiesel (Rehan, 2018). Addressing these challenges presents an opportunity for Saudi Arabia to enhance sustainability, reduce waste, and contribute to its economic growth.

A proposed novel strategy for landfilling for managing waste in KSA aims to enhance methane collection efficiency, leading to potential revenue generation and reduced fossil fuels reliance (Anjum et al., 2016). Investigations in laboratory involving indicated the presence of 99% methane and 1% other gases ( $\text{NH}_3$ ,  $\text{CO}$ ,  $\text{H}_2\text{S}$ , and  $\text{SO}_2$ ) at temperatures below  $50^\circ\text{C}$ .

Under the circumstances, a particular incubation period was identified as necessary for initiating the chemical degradation/gasification process. The study observed maximum methane production after 98 days, suggesting the climatic conditions in KSA could effectively help this process, even on a bigger scale (Alruqaie & Alharbi, 2013). Aligning with the country's Vision 2030, the installation of bio-refineries is deemed crucial for achieving environmental sustainability in Saudi Arabia (Alruqaie & Alharbi, 2013).

Alternative methods for converting food waste into environmentally friendly products include the generation of H<sub>2</sub> gas and biofertilizer through specific chemical processes (Khan, 2013; Miandad, 2017). However, in addition to technological management of food waste, raising awareness among residents is considered extremely important. A study involving 199 students yielded impressive results, underscoring the significance of community participation in addressing this environmental problem (Al-Zahrani & Baig, 2014; Alsawah, Saleh, Malibari, Lashin, & AlGhamdi, 2022). Complementary measures, including the provision of food banks, efficient storage systems, and food re-distribution initiatives, are deemed necessary to minimize waste.

While various facilities in Saudi Arabia are currently engaged in compost production, concerns have been raised about the quality not meeting international standards. Reports indicate issues such as unpleasant odor, less nutrient content, excessive metal presence, and higher pH levels in the produced compost, rendering it less effective for enhancing soil quality (Alzaydi, Alsolaimani, & Ramadan, 2013; Zajonc, 2014). Addressing these quality issues becomes imperative for maximizing the utility of compost in soil improvement endeavors.

Continuous Thermophilic Composting (CTC) emerges as groundbreaking technique for the swift breakdown of waste into stable carbon-based fertilizer, particularly well-suited for the extreme environmental conditions of KSA and other middle east countries, as argued by Waqas et al. in their study (M. Waqas, Almeelbi, T., & Nizami, A.-S. , 2018). Recognizing the unique challenges of desert climates, an initiative named Edama was established in 2017 to provide tailored waste recycling strategies.

Edama specializes in constructing and operating customized composting facilities designed for desert conditions as well as the agricultural requirements of desert regions. These facilities utilize the Turned Aerated Piles (TAP) system, offering a cheap approach to composting on a low scale. TAP system incorporates biofilters to control odor and employs other strategies to produce compost in a established manner, achieving stability in lesser duration (7-8 weeks). Edama's primary items include Edama Desert Compost, aimed at enhancing the quality of sandy soils, and Edama Palm Peat, designed to help robust plant survival.

In a trial conducted by Edama, the growth-enhancing effects of the compost were tested, revealing that Edama Desert Compost provided 5 times more plant biomaterial in comparison to the control group and its performance was way better than traditional manure (Edama, 2021). This innovative approach not only addresses food waste management but also contributes to sustainable agriculture in arid environments, showcasing the potential for environmentally friendly practices tailored to specific climatic conditions.

## **2.4 FW and food security**

Rome Declaration on World Food Security (FS) adopted in Rome, the city of Italy, in the World Food Summit which was held from November 13<sup>th</sup> to

17<sup>th</sup>, 1996, marked a significant milestone. This declaration reaffirmed the privilege of each individual for getting safer and nutritious food. Subsequent Plan of Action from the 1996 World Food Summit provided widely used description of FS, saying that it happens “when all people, at all times, have physical and economic access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active and healthy life” (FAO., 1996).

This term emphasizes global perspective of FS, covering whole human populace, and underscores the importance of sustainability. The term “all times” highlights the need for sustainability, aligning with the description regarding sustainable development, which aims that needs of the current generation are met without having any compromising terms on the propensity of the next generations meeting their demands (WCED, 1987). Despite a decrease in undernourished individuals from 1990-92 to the present, with 216 million fewer people experiencing undernourishment, 795 million people still have hunger issue (FAO., 2014). With an estimated additional 2.2 billion individuals by 2050, there is a pressing need for both increased food production and improved food system efficiency. Projections suggest a necessity to augment global food supply by at least 60% due to factors such as population growth, urbanization, and rising per capita income (Le Mouél, 2018). Addressing food waste (FW) is a crucial aspect, as cutting it in half could significantly narrow the difference between number of calories present in 2006 and those which are required in 2050 by 20%. (Searchinger, 2014) Furthermore, not losing only 1/4<sup>th</sup> of the 27river27t worldwide waste mass and redistribution could feed all undernourished people worldwide (FAOUN, 2016). To get worldwide FS seems like a complex issue which needs coordinated efforts from various stakeholders, including governments, international organizations, NGOs, farmers, food

businesses, retailers, and consumers. Undoubtedly, food waste is a critical factor in this global challenge, serving as a key milestone on the path to having global food safety (Z. Irani, & Sharif, A. M., 2016).

Food waste (FW) can significantly influence food security through two primary avenues. Firstly, FW reduction contributes positively to improving affordability of food by lowering prices. While there is a dearth of research establishing precise relationships of the quantity of wasted food and food prices, theory-based studies in economic perspective suggest that greater FW could result in increased food prices. In advanced countries, economic losses due to FW at the individual level may not severely affect livelihoods. However, in less developed countries, where food costs represent a substantial chunk of the domestic budget, FW can disproportionately affect food security (Timmermans, 2014).

The effect of FW decrease on food security has sparked debates. Some studies suggest that while reduction strategies can enhance food security, it remains unclear whether FW decrease can surpass other instruments including dietary shifts and production increases (Shafiee-Jood, 2016). In a study, (Springmann, 2018) analyzed FW reduction's contribution and stated that it is comparable to redistributing water and essential nutrients to close production gaps (Rutten, 2013). Studied dietary alterations and concluded that it has performance edge over FW reductions in the context of Gross domestic product (GDP) as well as the land use savings in the EU (European Union). Despite debates, FW reduction is recognized as an important auxiliary solution to tackle food security issues, coupled with strategies like yield increase and dietary shifts (Wani, 2024).

Second off, composting, and anaerobic digestion (AD) from FW could yield invaluable soil amendments, offering long-term benefits for food

security. Compost application enhances soil physical, chemical, and microbiological aspects, improving water retention, air exchange, and controlling plant pathogens with beneficial microorganisms (Albizzati, Rocchi, Cai, Tonini, & Astrup, 2022). These benefits contribute to establishing soil equilibrium, ultimately increasing food production. In contrast, linear models, such as landfilling, pose threats to food security due to their negative environmental impacts. Landfilling consumes significant land resources, causes pollution of water and air, and is detrimental to human health. Incineration, while generating electricity, releases toxic air pollutants (Dioxin) and produces fly ash containing harmful substances that, if mismanaged, can lead to land pollution (Bandala, Liu, Wijesiri, Zeidman, & Goonetilleke, 2021; Lebron, 2021). There are many studies and literature reviews analyzing the shift from linear to circular economic pathways. On the other hand, there is no concentrated research on turning the circular economy model into an operational solution but continues as a theoretical solution. The method that has been followed in the study by providing in-depth and comprehensive elucidating of the circular model, the advantages and disadvantages of current FWM (linear model), with the detailed assessment of linear model techniques and involvement circular economy solutions related to food security. The study also shows the difference in FW production mechanism between developed and developing countries (Y. Wang, Yuan, Z., & Tang, Y., 2021). Adopting circular models, which prioritize recycling and sustainability, is crucial for preserving food security by minimizing negative environmental impacts.

## **2.5 Food waste & environmental impacts**

Food waste poses significant environmental challenges, contributing to adverse impacts such as increased emissions of CO<sub>2</sub> and methane, leading to environmental impacts, increase in atmosphere acidity, eutrophication of

lakes, heightened use of water and energy, carcinogenic effects on soil, and occupying land. Here, we will examine and assess the environmental impacts of prevalent food waste tackling methods.

Landfilling, a traditional global method, is identified as ten times more potent in imparting a negative change in the climate and damaging human health compared to other methods including eutrophication, acidification, and incineration (Gao, Tian, Wang, Wennersten, & Sun, 2017; Lee, 2007). In the United States, landfills produce significant methane emissions, with a 25-fold greater impact on environment than CO<sub>2</sub> (Hall, 2009). Research reports highlight a substantial increase in food waste of 310 towards 510 kcal/cap/D, resulting in a more than 300% rise in greenhouse gas emissions of 130 to 530 Mt CO<sub>2</sub>eq/Y (Hiç, 2016). From 1961 to 2011, food waste multiplied threefold, contributing to a corresponding increase in greenhouse gas emissions from 680 Mt to 2.2 Gt CO<sub>2</sub>eq/ year (Porter, 2016). Developing economies, primarily generating waste from items related to vegetables and fruits, face challenges related to industrialization and the establishment of numerous food factories, potentially exacerbating global inequity (Weis, 2013).

The ecological impact of waste predominantly originates from upstream supply processes as well as inadequate waste managing practices. Considerable quantity of greenhouse gases, global warming potential (GWP) (Amicarelli, Lagioia, & Bux, 2021), acidification, eutrophication (Scherhauer, 2018), depletion of ozone (Mu, 2017), photochemically induced ozone synthesis (POF) (Fei, Jia, Chen, & Ling, 2021), reduction in abiotic components (Al-Rumaihi, McKay, Mackey, & Al-Ansari, 2020), human health degradation (Duret et al., 2019; Kibler, 2018), as well as land use (Usubiaga, 2018) are associated with FW (Scherhauer, 2018). Addressing these environmental concerns necessitates comprehensive

strategies over supply chain, emphasizing sustainable practices, waste reduction, and responsible waste management.

In Europe, food waste contributes significantly to emissions, with assessments indicating 15.7% global warming potential (GWP), 15.2% eutrophication and 15.1% acidifying potential. The products related to meat make the biggest contribution to environmental impact of waste from food (Scherhauer, 2018). The agricultural production sector in the United States heavily impacts the resources, in which energy and water are on top list. Food waste in U.S. requires an average energy equivalent to about 300 M barrels of fuel/Y and utilizes one-fourth of the freshwater, contributing to increasing global temperature (Hall, 2009).

In Turkey, footprints of the energy, carbon, and water associated with waste indicate that waste relate to energy constitutes 8% of total energy consumption annually. Additionally, water disposal from food waste alone is estimated to be twice the total national water consumption across all sectors, contributing to approximately 4% of total greenhouse gas emissions resulting from food waste (Cakar, Aydin, Varank, & Ozcan, 2020).

Composting FW emerges as a more environmentally beneficial alternative compared to landfills or other disposal methods for tackling organic waste. The method of composting not only provides eco-friendly means of waste disposal but also serves as amending the soil that improves soil texture without environmental impact associated with peat, a combustible material derived from wetlands (Saer, 2013).

In Qatar, two common composting techniques, windrow composting as well as anaerobic digestion (AD) composting, were analyzed to assess their environmental effects. Windrow composting exhibits a greater adverse effect than the latter in GWP and acidification domains. Conversely, the latter

has a more pronounced effect on individual's health toxicity domain (Al-Rumaihi et al., 2020). The choice of composting method should be carefully considered, taking into account the specific environmental factors and impacts associated with each technique.

Anaerobic digestion is a preferable treatment method in the context of preserving environment for recycling waste, producing fewer adverse effects compared to landfilling across all environmental impact categories (Tonini, 2018). Nevertheless, the use of digestate fertilizer, a byproduct of anaerobic digestion, could present a more sustainable alternative to chemical fertilizer with improvements in minimizing emissions and optimizing temperature and pH to prevent microbial activity (Chiew, Spångberg, Baky, Hansson, & Jönsson, 2015).

The valorization of food waste into biofuels or biochemicals is considered an eco-friendly treatment. In Sweden, the conversion of food waste into biogas demonstrates less ecological adverse impacts, contributing to the emergence of a bioeconomy (Brunklaus, Rex, Carlsson, & Berlin, 2018).

Animal feeding is viewed as a preferable option among various food waste treatment techniques due to its ability to minimize waste volume while providing climate and health related benefits. Nevertheless, the practice remains illegal in European countries, mainly due to the dearth of support from general public and the greater cost associated with its reintroduction (Salemdeeb, 2017).

Overall, the negative climatic effects of food waste require significant attention and efforts for mitigation through specific techniques. Conversely, preventing food waste in various service sectors imparts a positive environmental impact. Case studies in EU assessed the environmental benefits and effects of food waste prevention in various subsectors, revealing

substantial reductions in climate change and biodiversity impacts. Adopting a food waste reduction scenario resulted in mitigating over seventy percent of the repercussions on the climate and health (Beretta & Hellweg, 2019). Environmental effect investigations serve as valuable tools for food stakeholders for the purpose of comparing, pinpointing the gaps, and addressing critical spots in managing food waste.

## **2.6 Techniques to handle FW**

Despite the variety of methods of managing global food waste as described above, challenges persist due to mishandling and mismanagement, exacerbated by the continuous increase in food production and agriculture. To address these challenges, a combination of existing and innovative technologies is required for effective gathering of waste and disposing of it properly. Several strategies and recommendations have been proposed to avert a food waste catastrophe.

### **2.6.1 Zero Hunger Hero Method**

FAO outlines 9 procedures (Fig 4) to encourage reduced food waste and enhance public awareness, aiming to create Zero Hunger Heroes. These practices focus on achieving food sustainability, including consuming smaller portions, practicing dietary awareness, minimizing leftovers, and judicious shopping. Additionally, setting up compost bins for waste and donating excess food to those in need are recommended practices (FAO., 2017; Science, 2021). Social campaigns can play a crucial role in motivating individuals to adopt these steps, contributing to the realization of Sustainable Development Goals (SDGs) related to food waste.



Figure 4: Zero Hunger Hero Tips and Practices. Source: Constructed by the author

### **2.6.2 Managing FW sustainably**

Effective food waste management faces challenges such as scarcity of awareness among individuals, strict commercial policies, indifferent suppliers, and undertrained employees. Implementing sustainable management techniques is crucial to achieving more efficient food waste reduction (Filimonau & Gherbin, 2017).

A successful food waste management (FWM) strategy involves establishing a comprehensive system that integrates educating, motivating, and command-controlling techniques, incorporating regulations as well as stakeholder cooperation to formulate effective policies. The country Taiwan serves as an exemplary model, showcasing a comprehensive waste management system that significantly increases recycling activities, handling around 2,100 tons of waste on daily basis and generating substantial annual revenue (Thi, 2015). This integrated approach is especially crucial for sustainable FWM in developing countries.

Collaboration among scientists from various sectors is essential to develop environmentally friendly methods with minimal energy and water usage,

reduced waste production, and cost-effectiveness (P. Morone, Koutinas, A., Gathergood, N., Arshadi, M., & Matharu, A., 2019). Promulgating the Food-Energy-Water Nexus (FEW Nexus) within FWM represents a holistic and integrated sustainable management approach. This framework considers the impact of waste, its management, as well as post-disposal consequences. It emphasizes decreasing food waste, managing unavoidable waste, as well as engaging various stakeholders to work collectively. Comprehensive data analysis is essential to evaluate the entire process fairly (Kibler, 2018).

Network activity systems are effective management strategies aiming to enhance transparency between organizations and communities. These initiatives, such as donating, institutionalizing, and reducing food waste, demonstrate efficiency in achieving food security, supporting sustainable development goals in the area of consumption as well as production (SDG 12), providing quality donated food, promoting fresh and healthy options (SDG 2, 3, and 1), and involving diverse organizations in recycling of waste (SDG 17) (Moggi, 2018).

Raising awareness and knowledge through enhanced education is crucial in reducing food waste. The introduction of green alternative products and innovative distribution activities can add value for end-users and facilitate better understanding of social concerns within production as well as distribution network (Al-Obadi, Ayad, Pokharel, & Ayari, 2022).

Innovative management practices are important in achieving sustainable waste management. Incremental innovation involves gradual improvements, incorporating waste reduction processes leveraging advanced technology. Examples include green restaurants, doggy bag practices, and online sources for donating food (Martin-Rios, 2018). Preserving, such as

frozen foods, represents another incremental practice, with Austria demonstrating significantly lower waste from such foods compared to fresh food (Martindale, 2017).

On the other hand, radical innovation demands fresh knowledge and expertise, requiring substantial time, money, and effort for novel solutions. For instance, converting waste into energy demonstrates radical innovation (Martin-Rios, 2018). The Smart Garbage System (SGS) introduced contributes to efficient food waste management, reducing economic as well as ecological impacts of food waste, aligning with the idea of circular economy in entirety (Abdullah et al., 2022; Hong, 2014). Prioritizing prevention which is contingent on idea of environmental preservation is essential for managing waste sustainably (Cristóbal, Castellani, Manfredi, & Sala, 2018). First is prevention and later comes the redistribution to individuals in need, as it has low environmental impact and is cost-effective. Incineration along with landfilling are considered the final resort due to their huge ecological burden without any positive trajectory (Garcia-Garcia et al., 2015; Garcia-Garcia et al., 2017).

Categorizing FW sources is essential for determining the most efficient and environmentally friendly management strategies. Classification of FW revolves around 9 criteria including state, stage of supply, edibility, complexity, origin, animal product, level of the supply chain, packing, treatment, and biodegradability of packs. Each criterion requires tailored framework, taking into account various impacts, and the environment related, economic related, and societal consequences (Garcia-Garcia et al., 2015).

Fuzzy Cognitive Mapping FCM is a qualitative analysis technique introduced by Ozesmi and Ozesmi (2004). It is graphical modelling of complex causal relationships among various variables and a useful approach to

understanding how systems work. FCM is often used in ecological issues and environmental management. The basic steps FCM include: (a) drawing cognitive map for individual, (b) matrix interface by coding FCM into adjacency matrices, (c) gathering all individual FCMs into one social cognitive map, (d) examining the results of FCM, I simulating fuzzy inference (scenario interface) on the social cognitive maps (Özesmi & Özesmi, 2004). In Italy, FCM has carried out two environmental case studies: a land of fire and a valorization of organic waste. The aim of both cases is to improve policy strategies to enhance municipal waste management systems and to understand the participatory approach and causal relations among the stakeholders of the system in the country. The results identify the most effective strategies, such as excessive regulation, communication and information campaigns, and collaboration among supporting experts, should improve MWM systems by stimulating different scenarios based on studies (Falcone & De Rosa, 2020).

Improving food waste management (FWM) systems sustainably involves considering factors such as consumption of power, efficiency of the process, costs of the disposal etc. These elements collectively determine the overall cost of enhancing waste management the way that is both economically viable and environmentally responsible (Lee, 2007).

#### **2.6.2.1 The Food Waste Hierarchy**

The FWM hierarchy, derived of global waste management frameworks, notably introduced in European policies since the 1970s, has become a fundamental structure in addressing food waste. Other frameworks, such as Japan's emphasis on the '3Rs,' focusing on reducing, reusing, and recycling waste, share same approach to management (Shekdar, 2009). Primary goal of food waste hierarchy seems to prioritize ways that are there to yield the most favorable outcomes. The top of the pyramid highlights desired

options, ‘prevention,’ while at the other end is the less desirable option which is disposal at large. The European Waste Framework Directive (Parliament, 2010) aligns with this hierarchy (Fig 6).

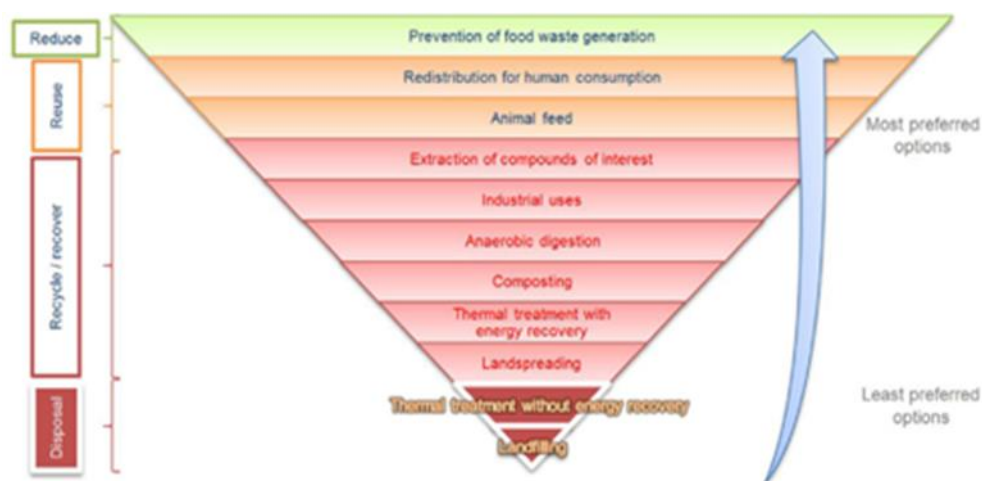


Figure 5: The Food Waste Hierarchy adopted from (Garcia-Garcia et al., 2017)

### 2.6.2.1.1 Reduction

The prevention of food waste (FW) is paramount at each step of the FSC, especially at consumer step. This preventive approach primarily applies to edible portions of surplus, recognizing that inedible parts will invariably contribute to FW. Positioned at the top of the recovery hierarchy, prevention is considered the biggest priority due to its significant resource and cost-saving potential. Research by ReFED on 27 spoiled food interventions in the United States emphasized cost-effectiveness of source reduction activities (REFED, 2016). Therefore, a distinction could be drawn between “strong prevention”, focusing on diminishing surplus at source, as well as “weak” prevention, centered on enhancing efficacy (Mourad, 2016). Acknowledging considerable amount of food wasted at the consumer level, various initiatives prioritize public communication to encourage consumers to minimize the waste, as exemplified by extension education programs

(Alhamdan, Hassan, Al-Kahtani, Younis, & Abdelkarim, 2016). A survey conducted by Food Drink Europe (2014) among 29 companies and associations revealed that well over eight percent of respondents were actively identifying causes of FW generation and optimizing. In an ideal scenario, FW generation needs to be curtailed through effective practices and measures across FSC, extending to the level of retailer's end. IGD recommends 6 steps for preventing FW production: measuring, engaging people, designing products and processes with waste-minimization in mind, selecting novel product ranges to eliminate waste, professing demand accurately, as well as reshaping processes for seamless product and information flows. Some FW produced in industry could be attributed to other levels in FSC, for example inaccurate forecasts by retailers leading to overproduction by food manufacturers. Retailers may also return unsold food close to its expiration date to manufacturers, shifting FW produced from the retail level to the level of manufacturing (Stuart, 2009).

- ▷ challenge in the interconnectedness of manufacturers as well as retailers is the short duration given to manufacturers for obliging when retailers modify the orders. Extending order times or reducing the time needed to produce food products can address this issue. For instance, some food industries adopt standard processes for common aspects (e.g., boiling rice) and do some special operations to impart various products their unique identity (Riesenegger, 2022).

Further prevention strategies are utilizing products of food with aesthetic issues differently than originally intended. For example, fruits with skin blemishes can be cut for use in convenience foods. Alongside this, industrial processes as well as their control ought to be optimized to minimize FW, such as reducing trimmings and minimizing burning during cooking.

### **2.6.2.1.2 Reuse**

Regarding FW management, ‘reuse’ refers to using surplus food as a food product, albeit not for its original purpose of being sold to the end consumer. This involves two main possibilities: one is the redistribution which is intended for human consumption whereas the second is the animal feeding.

#### **2.6.2.1.2.1 Redistribution**

In cases where a lot of food is being produced and is unavoidable, the desirable approach revolves around redistributing the wasted food for human consumption. This can involve repurposing for charitable causes, such as events intended for awareness or fundraising, or distributing it leveraging the idea of food banks. One feasibility study conducted by (Buksti, Fremming, Juul, Grandjean, & Christensen, 2015) explored setting up a technology system in Denmark connecting organizations with FW, like big markets, with entities including shelters for homeless. This system could facilitate the implementation of redistribution programs. (Bilska, Wrzosek, Kołożyn-Krajewska, & Krajewski, 2016) showed certain defective items as suitable for re-distributing, provided human health is not being affected by these. These include items with incorrect labeling, incorrect product weight, approaching expiration dates, and any untoward incident to the packages containing food items. (O’Connor, 2014) conducted a detailed investigation on the laws related to donation of food products in Europe. They recommended clarifications regarding value added taxes imposition on food donated and the establishment guidelines of EU for determining the actual lifetime of food products.

Prioritizing redistribution for preventable food waste, which is difficult to avoid, is advocated due to its evident social benefits and potential economic advantages for the donor persons (Giuseppe, Mario, & Cinzia,

2014). However, an evaluation by (Reynolds, 2015) scrutinized redistributing food in Australia and its economic and environmental implications. Surprisingly, their findings suggested that this approach might incur higher economic costs compared to alternative methods positioned lower in the FWH. This implies that while redistribution aligns with socially beneficial objectives, careful consideration of economic factors is essential to determine the most cost-effective and sustainable strategies in addressing food waste. The study highlights the complexity of the issue, indicating that a balanced approach is crucial in achieving both social and economic goals within the context of food waste management.

#### **2.6.2.1.2.2 Animal Feeding**

In cases where redistributing food to people is not a viable option, the alternative is repurposing it for animal feeding. (Parfitt, 2016) provided insightful recommendations for utilizing waste as feed of animals, emphasizing the suitability of food that has a high content of carbohydrates. Another study by (Tedesco, 2021) delved into the production of feeds from waste garnered from vegetables, employing various drying techniques like oven drying or microwaving. Their findings affirm that this kind of waste is perfectly suited for feeding without any hazardous elements (Chen, Jin, & Shen, 2015). Proposed another strategy to treat food waste with techniques including fermentation, heating, or a combination of these resulting in nutritious and valuable animal feed. However, they caution about the presence of contaminants like Pb, especially in the Chinese context, which may approach or exceed permissible levels for animal feeding. This suggests that careful attention to potential contaminants is crucial when considering food waste as animal feed.

In the United Kingdom, Feedback, an organization, is championing The Pig Idea campaign, advocating for the utilization of food waste to nurture

pigs while aiming to overturn ban on feeding catering food waste to these animals. Application of food waste in this context extends to various shapes and levels.

Over past few decades, persistent practices of animal farming have transitioned animal diets from grass and food waste to the items like imported proteins e.g. soya. Despite this shift, the economic benefits of using food waste for animal feeding remain significant, with food waste being sold for the production of animal feed from £30 to £50/ton (Parfitt, 2016). Such approach is also recognized for its environmental friendliness, with asserting that feeding pigs with food waste results in at least 20 times more CO<sub>2</sub> savings compared to its use in anaerobic digestion (Stuart, 2009). Furthermore, (Salemdeeb, 2017) showed repurposing FW as pig feed carries a lesser climatic effect compared to alternatives such as anaerobic digestion or composting.

#### **2.6.2.1.3 FW Recycling**

In case redistributing food waste is not possible, the next recommended option is to recycle it by obtaining alternative applications. This can involve extracting compounds which are important from food waste for future use in industries.

##### **2.6.2.1.3.1 Anaerobic Digestion**

While many food waste management strategies primarily target waste reduction, an alternative and sustainable approach involves valorizing food waste into value-added products. This includes the production of biofertilizers, biofuels, compost, polymers, and more (Fig 5). Biofertilizers contribute to better health of soil and can aid in water retention, particularly valuable in arid regions for enhancing food production. Bioenergy generated from food waste can help reduce reliance on fossil fuels, offering

environmental, social, and economic benefits (P. Morone, Koutinas, A., Gathergood, N., Arshadi, M., & Matharu, A., 2019). Extracting various compounds including proteins, fats, etc. from waste of plants using advanced techniques is also feasible (Garcia-Garcia et al., 2015).

Utilizing bio-products derived from food waste can contribute to the reduction of CO<sub>2</sub> emissions from landfills while helping conserve resources like fossils. This approach holds potential for offering multifaceted benefits across ecological, societal, and economic dimensions (Giroto, Alibardi, & Cossu, 2015). Incorporating high-tech, such as thermal and biological waste managing techniques, is essential for long-term food waste management due to their cost-effectiveness and environmental friendliness. Thermal treatment methods, including carbonization, fermentation, etc. as well as biological treatments like anaerobic digestion and composting, are among the recommended approaches (Ananno et al., 2020).

Anaerobic digestion stands out due to its cost-effectiveness, minimal waste generation, and transformation of waste into valuable resources including power generation, solid fuel, and heat recovery. The process involves hydrolysis owing to enzymes, acid formation, and production of methane gas with the help of certain bacteria to synthesize bio-based products while maintaining balance in the AD system (Paritosh, 2017).

As an instance, organism-based transformation presents an intriguing option by producing manure and dried larvae to produce enough feed, especially in aquaculture. 300 kg of larvae and 3,346 kg of compost could be generated via biotransformation with Black Soldier Fly Larvae (BSFL), such as *Hermetia illucens*, by ten tons of FW. Notably, BSFL decreases the weight of FW by half more rapidly than conventional composting methods. Furthermore, insect-based products serve as valuable resources for

biobased diesel production as well as organic fertilizers, contributing to a reduction in greenhouse gas emissions. The FWM system based on BSFL is recognized as an environmental-friendly technology with enormous benefits (Amrul et al., 2022; Salomone, 2017).

Microorganisms along with enzymes can play a crucial role in bioremediation techniques to repair damaged ecosystems and habitats. This approach involves converting harmful substances such as herbicides, pesticides, insecticides, and clearing chemicals into non-toxic forms, facilitating absorption into organisms and the environment. Bioremediation techniques find applications in various sectors of the food industry, including fruits, olive oil, vegetables, meat, dairy products, and poultry, proving effective in addressing environmental pollution caused by food industry waste (Mutebele, 2024; Thassitou, 2001).

In broader context, effective FWM ought to be conceived as a strategy which considers intellectual concerns, social constructionism, and organizational objectives, extending beyond mere FWM practices (Martin-Rios, 2018).

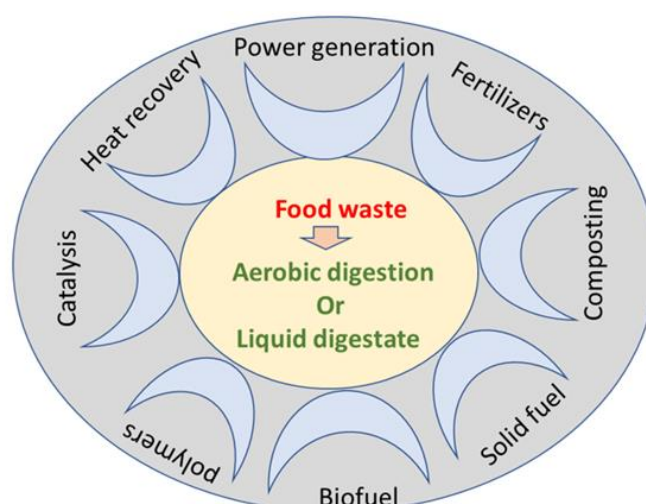


Figure 6: Value added products obtained from food waste management (AlQahtani, 2024).

### **2.6.2.1.3.2 Composting**

Composting, a biological phenomenon where bacteria transform waste into nutrient-rich compost, is a valuable soil enhancer. Composting relies on microorganisms that utilize oxygen in their metabolic processes. This method can be implemented at both industrial facilities and households. In industrial settings, composting may occur in various types of instruments e.g. vessels, silos etc. Notably, in-vessel composting encompasses the sole method for composting commercial food waste which encounter the animal products (Ayilara, Olanrewaju, Babalola, & Odeyemi, 2020).

Composting offers several advantages as a waste treatment option. It is cost-effective, eliminating the need for tipping fees, generates revenue from the produced compost, and can reduce waste volume by up to forty percent (Czekała, Nowak, & Bojarski, 2023).

(Li, 2023) highlighted significance of culture, initial material which initiates the process, being a crucial factor influencing the maturity of compost; aeration rate also plays a key role. Achieving an optimal feedstock composition may require blending various raw materials, such as bulking agents to enhance composting efficiency (Zahra, 2023). To ensure the quality of compost, WRAP has developed a Quality Protocol that outlines criteria for compost production and utilization. Additionally, WRAP has produced guidelines for various stakeholders to facilitate successful composting processes (WRAP., 2016).

Addressing food waste at its source, particularly during food preparation and collection, is key to reducing overall waste generation. Composting under desirable conditions and in-sink processors that process and shred waste are suggested for home use due to their low environmental impact and cost-effectiveness (Dilkes-Hoffman et al., 2018; Gao et al., 2017).

The anaerobic composting process does not require oxygen to occur. Anaerobic decomposition involves the use of anaerobic microorganisms to break down FW compounds. Nitrogen, Phosphorus, and other nutrients are used in the process to develop cell protoplasm. A large amount of carbon is released as methane gas (CH<sub>4</sub>), and a small amount of carbon can be absorbed as CO<sub>2</sub>. The most important part in the anaerobic phase is breaking the halogenated hydrocarbons linked with conservation of nitrogen (Czekała et al., 2023).

The main factors affecting the anaerobic composting process include temperature (35°C), pH value (6.8-7.2), methanogenic substrate concentration, anaerobic pathogens.

Hydrolysis, acidogenesis, acetogenesis and methanogenesis are the four main stages in the anaerobic composting process. The first stage (hydrolysis) involves fermentation microorganisms breaking down complex organic substances such as cellulose into simple, soluble molecules such as amino acids and sugars. The second stage (acidogenesis) involves an additional breakdown of remaining complex molecules. The third stage (acetogenesis) is more digested via bacteria such as *Clostridium aceticum*, *Acetobacter woodii*, and *Clostridium thermoautotrophicum* until create acetic acid, carbon dioxide, and hydrogen. The final stage (methanogenesis) is methane production by bacteria named methane formers such as *Methanosarcina* (Mehta & Kanak Sirari, 2018).

#### **2.6.2.1.4 Recovery**

When food waste (FW) cannot be recycled, maximizing the impact received from it becomes essential. Some of the important options for recovering impact from waste include land spreading and energy recovery.

#### **2.6.2.1.4.1 Thermal Treatments Induced Recovery of Energy**

Thermal process encompasses various steps such as pyrolysis, incineration, as well as gasification, differing owing to the extent of the temperature employed and the type of substance gained. Gasification involves obtaining syngas, consisting mainly of CO and H<sub>2</sub> gas. The residue left behind is called char and ash. Gasification typically occurs at temperatures greater than 700 °C with limited amounts of steam as well as oxygen (Arvanitoyannis, 2010). Such processes aim to get power with respect to producing electricity along with heat energy (Son, 2023). Not only this, bottom ash and residues from devices intended to control air pollution may find value in subsequent industry-based applications. Incineration involves burning waste at temperatures of 870-1200 °C, causing material to convert into gaseous phase. Some of the gases include CO<sub>2</sub>, H<sub>2</sub>O, CO, Nox, and more substances. The rest of the material is called ash as well as slag. Moreover, similar to incineration but at high pressure, pyrolysis occurs at above 430 °C along with the condition of absence of air. Gases produced include CO, H<sub>2</sub>, CH<sub>4</sub>, and other related hydrocarbons. Another residue called coke is also obtained. It has been shown that this process is more suitable and less harmful than pyrolysis, albeit requiring a time-taking process duration (Mlonka-Mędrala, 2021).

Additionally, hydrothermal carbonization, attracting increased attention, is advantageous for treating high-moisture waste, producing highly energy and dense substance known as hydrochar. Such procedures could potentially be imparted to all types of waste but are better economically for applying to dry waste (Pham, 2015).

While thermal treatments have lower efficiency compared to coal-fired power stations and produce pollutants harmful to health and the environment (FAO., 2013), they serve as a renewable alternative to fossil fuels.

Though costly and associated with environmental and social impacts, these methods reduce waste volume and eliminate potentially harmful substances, including pathogens (Brunner & Rechberger, 2015). Despite cost-saving potential through offsetting traditional fuel use and reducing disposal costs, the high-water content in FW makes it less suitable for thermal treatments (Guran, 2018).

Various thermal treatments are often conducted sequentially or combined with other FW management systems. For instance, pyrolysis followed by gasification or using pyrolysis to process digestate from anaerobic digestion (Y. Wang, Yu, G., Xie, S., Jiang, R., Li, C., & Xing, Z., 2023).

#### **2.6.2.1.4.2 Land Spreading**

Land spreading involves applying organic material, typically waste, to the land to enhance soil nutrient content, improving attributes of soil and reducing need for artificial fertilizers. At farm level, land spreading could be advantageous as farmers can directly apply FW, to the soil, eliminating the need for storage and transport (Agency, 2015). There are several hazards related to land spreading and mainly include chemical hazards and microbial hazards. The microbes including bacteria, viruses, parasites and the chemicals include pollutants related to organics, heavy metals, detergents, medicinal compounds, illegal drugs, endotoxins etc.(Beggio et al., 2021).

#### **2.6.2.1.5 Disposal**

Disposal of waste is the least favorable treatment in Food Waste Hierarchy, emphasizing that it should be avoided whenever possible. This stage involves simple landfilling as well as temperature treatment.

#### **2.6.2.1.5.1 Thermal Treatment Avoiding Recovery of Energy (Incineration)**

Incineration involves burning waste in the presence of air leading to the production of a residue called char. While char could be repurposed as a fuel or a soil alteration, the process lacks energy recovery as the heat is gone. Gases produced are toxic and contribute to the emission of greenhouse gases. Due to its detrimental environmental impact and air pollution, thermal treatment is discouraged, especially in developed countries where its practice is strictly regulated (Maalouf, 2023). In developing areas, it is more commonly used, often involving a mixture of FW with other consumer waste in Municipal Solid Waste (MSW) processing (Saravanan, 2023).

#### **2.6.2.1.5.2 Landfilling**

Landfilling involves depositing waste onto or into the land, causing significant environmental impact. Microorganisms decompose matter, producing CH<sub>4</sub> and CO<sub>2</sub> that enhance greenhouse impact. Though gases emitted can be collected for energy production in well-managed landfills, the process generates toxic compounds that contaminate essential resources, posing health risks. While landfilling is discouraged owing to its environmental consequences and dearth of socio-economic profits, it is considered a better option than illegal practices like open dumping and fly-tipping. In the UK, for instance, where such practices are illegal, there were 900,000 fly-tipping incidents in 2014-15, with a cost amounting to £50 million to authorities (Pasalari, 2019; Tauringana, 2015).

### **2.7 Legislative Laws**

Addressing the challenge of waste management produced by food alone involves the implementation of legislations and laws across different regions. The four R's including Reduce, Reuse, Recycle, as well as Recover-

are considered key principles in waste hierarchy, guiding efforts to minimize and manage food waste. Successful food waste reduction strategies require collaboration among various stakeholders including individuals, society as well as states necessitating a shift in cultural waste disposal practices (Al-Qahtani, Wuhayb, Manaa, Younis, & Sehar, 2021).

In Japan, in 2021 a law related to food recycling was adopted encouraging manufacturers and emitters to convert waste into biogas, compost, as well as animal feed through incineration. To further emphasize the importance of food recycling, the law got some amendments in 2007, introducing the concept of “Loop Recycling.” This allows facilities intended for recycling to gather and transport waste via municipal borders, adding a requirement for buying products from farms that employ waste-derived items, completing the recycling loop effectively (Takata, 2012). The law facilitates increased gathering and recycling of waste, offering environmentally beneficial and cost-effective solutions. Different procedures, such as dry-feeding as well as bio-gasification, contribute to reduce GWPs, influenced by factors like energy usage, food waste moisture, along with recycled materials in animal feed facilities (Takata, 2012).

In the USA, various states have implemented legislations and strategies to restrict the landfill disposal of food waste. These laws emphasize source segregation and introduce recycling plans for businesses, institutions, and residences acting as food waste producers (Hodge, 2016). Similarly, the Korean government implemented stringent legislations, including source sorting of food waste and the introduction of a volume-based charge system. These measures have led to a gradual decrease in food waste generation since 1998. In 2005, the ban on landfills, which previously accounted for over 90% of waste of food, was substituted by a recycling paradigm (Lee, 2007).

Several countries in Asia, Europe and other continents have implemented laws aimed at achieving sustainable food waste management. In Brazil, goal is to eliminate all of the places for dumping that are open by 2014 and sort and gather 36% of waste that could be recycled as well as 53% of FW by 2030. Moreover, in Turkey, legislation mandates using procedures like composting and use of methane for generation of power to reduce land-filling of food waste (Thi, 2015).

However, many countries worldwide still lack comprehensive food waste management policies or programs. In KSA, food-based waste recycling has started, but a small chunk of the waste is processed through informal activities. In the Eastern Province of KSA, a food waste recycling program encourages individuals to make lesser amount of cooked food, cutting on food waste. Despite these efforts, the absence of laws, prevalent landfilling practices, negative public views, and uncertainty about public acceptability remain challenges. Without additional stringent regulations or laws, KSA's annual municipal solid waste and food waste could increase to 6.7 million tons by 2032 (Mu'azu, 2019).

In Bangladesh, we don't see law governing the changes in the municipal solid waste system. There is no provision of separating out the organic waste from rest of the waste and is typically intermixed with municipal garbage. Municipal solid waste management continues to rely on conventional landfilling managed by municipalities, alongside a community initiative encouraging voluntary waste disposal and an informal system employing informal labor for waste disposal (Ananno et al., 2020).

## **2.8 Circular bioeconomy**

The circular bioeconomy approach integrates concepts of bioeconomy and circular economy into economic activities. The circular economy, as

outlined in the Circular Economy Action Plan, intends to conserve the impact of raw materials or products in economy for an extended duration through waste tackling practices such as sharing, redistributing, reusing, and recycling. This process results in the production of secondary products with reduced waste and carbon dioxide emissions. Bioeconomy involves generating renewable resources and making them into valued products, including food, bio-based products, animal feed, along with bioenergy (EuropeanCommission, 2015; Mak, 2020).

The conversion of food waste connects the bioeconomy with the circular economy via directing waste toward recycling, recovery of energy, or disposal by landfilling. This intersection gives rise to the concept of Circular Bioeconomy (CBE), which represents the synergy between circular economy and bioeconomy principles, aiming to improve resource efficiency and environmental sustainability. The focus of CBE is on reducing greenhouse gas (GHG) footprints, meeting fossil fuel demands also valorizing waste streams. The shared objectives include enhancing resource utilization efficiency, valorizing waste, and decreasing greenhouse gas emission during production and extracting process (Mak, 2020).

As an instance, FW components like fly ash as well as eggshell could be repurposed for use in industry, such as removing heavy metals from wastewater. These materials are characterized by their cost-effectiveness, reusability, mass usability, environment-friendliness, and increased capabilities (Segneanu, 2022).

A circular bioeconomy which is sustainable and is contingent on the biomass holds promise to handle global environmental challenges, including climate change, growth of population, limited resources, as well the growing demand for meals. However, going from a linear economy towards

circular bioeconomy requires closed-loop models in food waste management, incorporating efficient and cost-effective technologies with environmental considerations (Almulhim, 2024; Mak, 2020).

KSA and Gulf Countries (GCC) have currently aligned with the concept of linear economy regarding FW management. For example, in the city of Makkah, a projected increase in waste to 1.60 million tons by the year 2030 prompts the exploration of circular economy principles. If circular economy practices like composting were implemented in Makkah, it could generate roughly 0.23-0.40 M tons of the compost, leading to a total revenue amounting to 240-419 million SAR and changing of 124-216 kilotons of fertilizers with credits reaching 74-129 M SAR from the years 2015 to 2030. By adopting compost technology could save 618-1078 M SAR crediting related carbon as well as landfill, along with reducing 0.043-0.076 M tons of methane gas, contributing a total revenue amounting to 1626 M SAR in 2030. This paradigm suggests a pathway for decision-makers to establish waste management which is sustainable(Rashid, 2021).

## **2.9 Literature Conclusion**

The conclusion of this chapter includes two summaries:

### **2.9.1 Executive summary of previous studies**

The earlier studies of this chapter have been focused on several points:

- Comprehensive definitions of different terms related to food waste, loss, and surplus. The studies revealed that there are no clear or unify global agreement for food waste terminologies which considers the main gap in many countries' understanding and recognition of various types of food waste and how they are managed differently.

- Reviewing the current situation of FWM in Saudi Arabia and the causal relationships that lead to the high levels of food waste in the country. Providing potential proposed scenarios that could increase the economic growth, power if the country adopts sustainable management, performances, practices, and approaches in context of FW.
- Raising awareness of FWM among consumers, retailers and other food stakeholders is critical to the successful implementation of sustainable FWM and new strategies in the country.
- Reviewing the environmental issues relate to FW. Greenhouse gases, climate change, acidification, eutrophication, water and energy consumption, and land occupation. Discussing the potential environmental impacts of different food waste treatment technologies (landfill, incineration, anaerobic digestion, composting, animal rearing, and thermal interaction).
- An overview of food security and FW.
- Synopsis different laws and regulations around the world, whether or not they are sufficient to implement in KSA.
- Reviewing various sustainable management alternatives, for instance, the waste hierarchy, incremental, and radical innovations to tackle FW problem and support the principle of circular economy. Exploring some strategies to overcome FW generation and unsustainable management
- Reviewing different methodologies and software tools to improve the interventions among stakeholders 'activities and public for establishing social and environmental integrated approach.

## **2.9.2 Chapter Summary**

This chapter demonstrates the ambiguity and complexity of definitions that exist in the literature on food waste by outlining differences in food waste terminology and classification within the food supply chain. Therefore, this clarification helps this research to define the direction and boundaries of the work (downstream of the FSC). This helps to understand literature review gaps and challenges related to implementing food waste management in different countries. For example, in the European region, by-products, animal feed and biorefineries are not considered waste; although they occupy 70% of total waste, they are not counted in FW (R. Jones, Speight, R., Blinco, J., & O'Hara, I., 2022; Torok, 2021). Therefore, agreement on internationally unified definitions and classifications will enhance food waste prevention. The chapter gives a synopsis of the Saudi's food waste producing and situation of FWM in the country. It encourages us to form and structure this research.

The literature chapter presents a selection of research methodologies, alternatives and software tools that help to decide and adopt methodological approach for this research with making some justifications on selected approaches.

The next chapter shows the methods and procedures that have been followed in this thesis that they can identify the most sustainable alternatives FWM in the retail sectors and understanding the knowledge gap among the food stakeholders in context of FWM.

## **Chapter 3: Methods and Procedures**

### **3.1 Introduction**

This chapter provides different research types and approaches that have been considered and justified in this research as shown in (Fig7). It outlines the phases in the development of research procedure that have been followed to address the research objectives as shown in (Fig 8). The objectives have been organized and aligned with the research methodologies and results as shown in Table 4).

### **3.2 Research Strategy**

Research strategy provides the pathway a research construction. It considers the nature of the research problem and previous research to plan the selection of methods, collection and analysis of data. Research results depend on the proper choice of research methods (Fellows & Liu, 2021). In this section, the various methods used in this study are described.

#### **3.2.1 Analytical research**

Analytical research emphasis on the “why” of the study problem more than the “what.” It is a critical analysis of the information available on the existing situation (Pedamkar, 2023). In this research, the aim of the analytical method is investigating the current the FWM practices, analyzing the issues and challenges related to topic, and trying to suggest suitable FWM solutions with sustainability criteria.

### **3.2.2 Fundamental research**

Fundamental research focuses on understanding and observing environmental problems, setting scenarios to predict their future performance, and combining this information with existing knowledge related to the topic (Fellows & Liu, 2021). In the present research, the fundamental research method attempts to advance FWM to prevent and reduce the current FW generation at the downstream food supply chain. It encourages food retailers to develop eco-green projects, such as composting and waste to energy, as alternatives for the industry, whether or not they implement these solutions. Furthermore, the scenarios predicted from its performance are estimated by using computer-based modelling and simulation (FCM) rather than research laboratory-based.

### **3.2.3 Qualitative research**

Qualitative method is related to non-numerical data in the research. This type of method explores and investigates the motivational factors behind social behaviors, beliefs, opinions in depth (Almalki, 2016). It's may include surveys, interviews, and observations. Data from this type are rich, flexible as researchers can modify questions and settings relevant to the topic and are useful tools for social and business research. However, it's used for small sample sizes, unstructured data, and difficult to analysis (Fellows & Liu, 2021). In this research, the qualitative research is used for understanding the public attitudes, awareness, motivated variables of existing FWM, FCM simulation, and classification FW types.

### **3.2.4 Quantitative research**

Quantitative research is related to numerical data in the research. It's gathering data from questionnaires, experiments or desktop research using available data (Creswell, 2014). It draws the data into grids, facts, and

graphs. It's useful tools for scientific and field-based studies. The advantages of quantitative research are the use of large sample size, accuracy, and privacy of data, as the anonymization of information and data analysis is quite quick and easy compared to qualitative data. However, quantitative methods may not reflect participants' responses actual beliefs. It's also limited due to survey responses (Pedamkar, 2023). In this research, quantitative method is used to estimate public awareness related to FWM via using questionnaires to attain a numerical description, statistical analysis of mean, Standard deviation (SD) attitudes via studying a sample of participants and get the quantity of wasted food in retail sectors.

Besides to the main four types of research methods that aforementioned, the present research embeds different aspects of research such as simulation research and field-setting research. The modelling and simulating research investigates the stakeholders' perspectives in regard of FWM and the factors that might alter FWM practices currently applied in the food retail sector. The present research is used field-setting research that involves industrial visits, data collection, and consultation with academia staff and interview industry demand and supply employee from various food retailers. In addition, the present research has included multi method approaches, which are involved several phases to significantly address the aim and the objectives of this research.

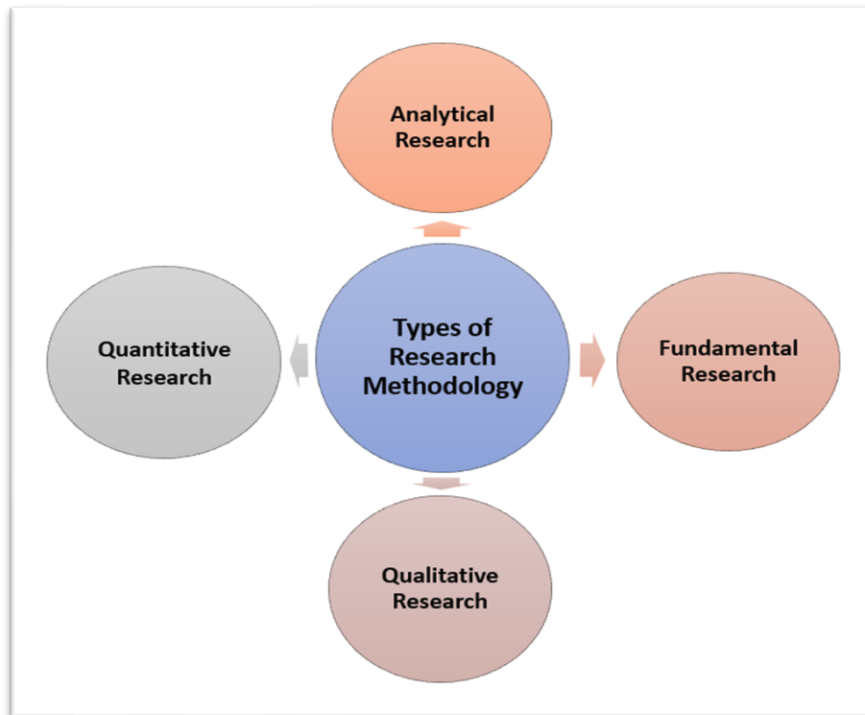


Figure 7: The types of the methodologies adopted in this research. Source: Constructed by the author

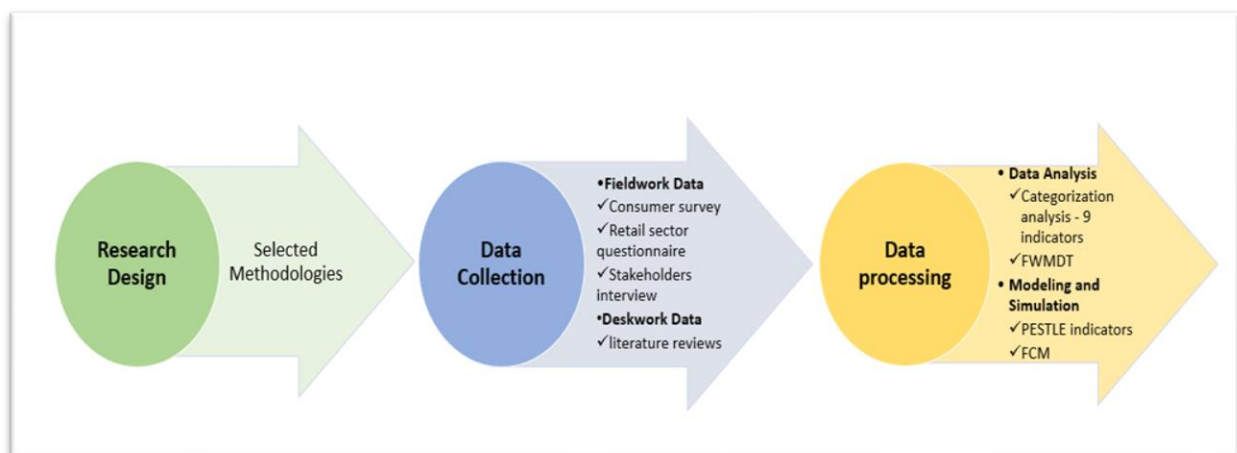


Figure 8: Phases of the research methodology. Source: Constructed by the author

### **3.3 Data Collection**

Data collection is a communication process that transfers information from participants (providers) to researchers (collectors) (Fellows & Liu, 2021). It's an approach that occurs in the early stage of research and depends on the type of data collection the research method would be constructed (Naoum, 2013). In this study, two types of data, primary data and secondary data, are used.

#### **3.3.1 Primary data collection (Fieldwork)**

Primary data or called fieldwork because it requires social interaction and observation in natural life. Primary data refers to collected information that gathers for the first-time on a certain topic (Hox, 2005). In present research, the primary data includes survey, interview, and field site visits as listed below.

##### **3.3.1.1 Consumer survey**

In this research, data were collected from the survey for assessment and analyzing of the public awareness on food waste management (FWM) (Di Talia, Simeone, & Scarpato, 2019; Pinto, 2018).

During the survey preparation phase, survey questions were prepared and pre-tested to collect data from consumers. The wide cross-sectional survey, conducted between October and December 2022, was conducted through an online Google Form and collected 402 respondents from five regions in Saudi Arabia and other countries. The survey link was shared among the population through social media networks (WhatsApp, Twitter, and Instagram accounts) then the responses were simultaneously updated in an Excel sheet.

In the survey design stage, the survey involved of 45 multiple-choice questions into four sections (Appendix1). It entailed closed-ended answers to

investigate different aspects of the respondents. First section was related to general information of the participants (gender, age, education level, profession, marital status, number of family members in the household, monthly income, and nationality). Second section of questions were related to assess the respondents' awareness of FW impacts and explore what are the ways that respondents prefer to get more information about food waste problem and how can reduce it. Third section questions were estimated the respondents' knowledge of FWM and their willing to accept new regulations and practices which could correct ineffectiveness of the existing habits. The last section was highlighted the respondents' food consumption behaviors and the key causes of FW.

### **3.3.1.2 Retail sector questionnaire**

The purpose of the company questionnaire is to describe the current management situation of FW. In addition to identifying and categorizing selected FW types in the retail industry, sustainable alternative solutions can be designed for companies that contributed to the current study. The questionnaire was structured and developed before visited the sites of 10 companies in Al Khobar city. Although there are already many food companies in a developing city like Al Khobar, I have listed 10 companies based on the size and scale of the targeted business. However, only 3 of the companies were accepted and filled out the forms by the managers and directors of the top management staff of their companies. The rest of the companies declined because of fears their data would be used against them.

The questionnaire consisted of 14 questions, both qualitative and quantitative (Appendix 2). Qualitative questions were asked to determine each company's performance in terms of FWM based on nine indicators, namely

Edibility, State, Origin, Complexity, Animal product presence, Treatment, Packaging, Packaging biodegradability.

The quantitative questions were asked the directors' opinion about investment in the FW, and when and why the food waste is mostly generated during the year. Quantitative questions, on the other hand, ask for an estimate of the average amount of each type of food waste generated by each food company each year.

### **3.3.1.3 Stakeholders visit and interview**

The stakeholder assessment in this research includes field visits and in-person interviews with food chain stakeholders in private sector (retail stages), Zoom online meetings with a group of academic staff (4 members) in Food security/Agricultural business administration from King Faisal University (KFU). Relevant local officials from the Saudi Recycling Company (SRIC), the National Waste Management Center (MWAN), the Ministry of Environment, Water and Agriculture were interviewed via phone, email and online meetings. Unfortunately, however, there was no collaboration from local authorities other than (SRIC) to participate in this study. The stakeholder's data collection took 8 months to complete, with an average length of 90 minutes per interview. The interviews involved questions, forms and an elaboration of the concept of indicator assessment, why the study was conducted and the software that would be used during the interviews. The location, date, time and duration, and the names of the contributors, their gender, and job role were stated.

The stakeholders were asked qualitative questions to find out more about their role's interactions, arrangements, cooperation among them, regulations, and performance in order to achieve sustainable development in regard of FWM and reduction. The content of the assessment is explained in the section 3.4.2 below.

### **3.3.2 Secondary data collection (deskwork)**

Secondary data or known as desk work is obtained from other sources. Secondary data can be formed either in a statistical or descriptive structure. Saving time and cost are the most significant advantages of secondary data over primary data collection (Naoum, 2013).

The secondary data of this research were literature reviews and archive documents that collected from a different resources for instance, e-government authorities, companies' records, notes of interviewees meeting published data, reports, and studies from domestic and international institutions such as MEWA, FAO and World Bank, etc.

The first step in the present research was reviewed the relevant literatures and documents 1 about FW definition and research problems, the issues of food waste production and management, influence factors on FWM in KSA, tools and alternatives to solve unsustainable FWM, a review of existing strategies, policies and operational practices in the country, and different types of research have been carried out to enabled to analyze the research scope and objectives. This outline is presented in published paper1.

## **3.4 Phases of the research analysis**

In this section, the data analysis consists of three parts: survey analysis, categorization analysis approach, and Modelling and simulation.

### **3.4.1 Survey Analysis**

Consumer survey data analysis was carried out by SPSS Statistics (version 29). Descriptive statistics and cross-sectional study conducted to calculate the frequencies, proportions to describe categorical data such as sociodemographic variables, respondent's knowledge, awareness, and their attitudes toward FWM. It also calculated the P-value of the respondents by logistic

regression where the significance level was  $P < 0.05$ . In this research, the empirical analysis was carried out on an online survey as aforementioned that has several advantages: an online survey enable research to be disseminated overseas and easily accessible to assess public awareness, knowledge and practice of FWM. It's free, flexible administration time. Due to confidentiality, optional survey, and anonymous contributors, it helps gain the trust of the interviewee compared to face-to-face interviews. The online survey also had closed-ended questions (multiple choice only), which may help reduce errors by controlling for incorrect interpretations.

### **3.4.2 Categorization analysis approach**

Categorization is a fundamental step in elaborating the various types of food waste generated at the consumer and retail stages. Additionally, there is a need to identify the best food waste management alternatives to mitigate environmental impacts and increase the economic and social benefits of utilizing FW. In the present research, the categorization approach was adopted from (Garcia-Garcia, 2017) and justified to suite the research scope.

It was implemented only for seven selected groups of food waste types, as they are the most wasted food at the consumer and retail stages:

1. Fruit and vegetable
2. Canned food involves plant or animal products
3. Eggs and dairy foods include cheese, cream, butter, and yogurt
4. Raw red and white meats include cow, lamb, chicken, and fish
5. Cereals and grains include rice, pasta, corn, oats, and wheat.

6. Bread involves all food that prepared from dough of flour such as (loaf, rusk, baguette....etc.)

7. Ready meals (Grocery's bakery and cafeteria food) which include the cooked food which mainly frozen or dried without need of using raw ingredients in process.

Frozen foods and beverages were excluded from this study. The purpose of the FW classification approach is to provide a framework or strategy to design the most appropriate management options, bridge knowledge gaps in FWM and optimize decision makers.

### **3.4.2.1 Nine indicators for categorization FW**

Prioritizing the most appropriate management options requires indicators. As aforementioned, there are nine indicators (Edibility, State, Origin, Complexity, Animal product presence, Treatment, Packaging, Packaging biodegradability) that can be used in this assessment. In this section is described each indicator below and in (Appendix 3).

**1. Edibility:** it divides into two types: edible and inedible FW.

The edible is all food waste that can be used for human consumption such as bread, cucumber...etc, otherwise, the FW is considered inedible such as meat bones and fruit peels. If the food waste has both edible and inedible parts such as oranges and its peels in this case is considered edible. Therefore, there are some considerations in the edibility indicator of some FW and its edible and inedible parts can vary based on time and geographical area.

**2. State:** This indicator only applies to edible products. State indicator classifies FW into eatable and uneatable. The eatable FW is not lost its properties and fit to be consumed by human at the point of its management as waste; otherwise, the FW is uneatable such as passing the

food its expiration date, spill during distribution, etc. When the product has both eatable and uneatable parts, it is considered uneatable.

3. **Origin:** This indicator includes an animal-based product and plant-based product. The animal-based is either the products that are generated by an animal such as eggs and dairy products or from parts of the animal such as meat; otherwise, the product is plant based. In some type of FW such as ready meals have both plant and animal-based products. In this case, it should classify based on its dominant ingredient.
4. **Complexity:** This indicator only applies to plant-based products. It involves single and mixed products. A single product contains only one material; otherwise, products would be mixed.
5. **Animal product presence:** This indicator applies to animal-based products. It categorizes the products into three categories: as meat, animal product when the product is produced by animals such as eggs and dairy products, and animal by product (slaughterhouse) that is produced from animal bodies not for human consumption such as bones, skins, etc.
6. **Treatment:** This indicator only applies to edible and edible FW. It involves Processed and unprocessed products. The processed contains the final product to be consumed and not need any processing prior to being sold such as a ready meal and fresh fruits and vegetables; otherwise, the product unprocessed.
7. **Packaging:** It contains packaged and unpackaged products. The Packaged FW contains packaging material such as canned food; otherwise, the product is unpackaged.
8. **Packaging biodegradability:** It only applies to packaged products. Biodegradable packaging refers to packaging made from materials

such as paper, wood, bioplastics, etc. that can be digested by microorganisms and suitable for composting; otherwise, packaging is non-biodegradable, such as plastic, glass or metal.

9. **Supply chain stage:** This indicator relates to catering and non-catering FW. Catering food waste refers to all food waste generated by catering service institutions such as restaurants, schools, hospitals, etc. While non-catering food waste occurs at the agricultural stage, manufacturing, distribution, and retail stages.

#### **3.4.2.2 Food Waste Management Decision Tree (FWMDT)**

After analyzing and categorizing the FW types based on nine indicators that discussed above, FWMDT has been designed to identify and prioritize the sustainable FWM solution and alternatives. In this research, it applied for seven types of FW that mentioned in section (3.4.2).

The FWMDT is a flowchart or (Tree) that helps the user to choose the appropriate indicator that describes its FW type. The user should start from the highest level of the flowchart. Then, the user would move through subsequent levels of the flowchart (Appendix 4 and 5), following the arrows and select more indicators until reach the bottom of the tree. In at the bottom of the flowchart, there are a different collection of sustainable FWM solutions based on the variety of indicators for that food type. In addition, FWMDT has adopted classification and separation strategies, such as separating plant-based products from animal-based products. Sorting and separation strategies provide more alternatives for targeted management practices for different food waste types.

FWMDT is derived from the food waste hierarchy (FWH) discussed in Chapter 2. FWMDT includes five management techniques: redistribution, animal feeding, anaerobic digestion, composting and thermal treatment

with energy recovery. Preventing FW production was not involved in the FWMDT due to several reasons: food waste prevention is always the top option of the FWH and should be always prioritized, it is an applicable option for all kind of edible FW. Therefore, there is no need to present this option in FWMDT, at last in retail sector the FW was already created and required proper FWM. Landfilling and incineration were also excluded from FWMDT as they have significant adverse effects on environmental, economic and social outcomes.

### **3.4.3 Modelling and Simulation**

Modelling is the process and virtual representation of specific substances in a simple manner (Maria, 1997). The modelling is the base line of simulation. Simulation is a system that uses the model's variables to predict their behaviors under certain circumstances in a realistic way. It assists to improve a model and its predictive capability and conditions (Fellows & Liu, 2021). In this study, modelling and simulations were carried out and described as follows.

#### **3.4.3.1 PESTLE indicators**

PESTLE is indicators and tools to identify Political, Economic, Social, Technological, Legal and Environmental factors (PESTLE) (Bhuiyan, Zhang, Xuan, Rahman, & Khare, 2023; Z. Irani, Sharif, A. M., Lee, H., Aktas, E., Topaloğlu, Z., van't Wout, T., & Huda,, 2018; Mukhtar, 2017; Zalengera, 2014; N. Zhang, Williams, I., Kemp, S., & Smith, N., 2011).

In this phase of research includes two stages. The first stage was collected a list of variables and factors that have influenced FWM from peer-reviewed literature and grey literature such as reports, guidelines, website, etc. Second stage was classified and grouped the factors of the results of the first stage into PESTLE indicators. It is defined below.

- 1) Political factors (P): which are highlighted the government interventions, policies and laws that may affect KSA-FWM.
- 2) Economic factors I: which are highlighted essential points that influence sustainable KSA-FWM from an economic perspective.
- 3) Social factors (S): which are highlighted essential points that influence sustainable KSA-FWM from a social perspective.
- 4) Technological factors (T): which are reflected innovative managements that possibly effecting KSA-FWM development.
- 5) Legal factors (L): which are stakeholder's responsibilities to comply food waste management guidelines.
- 6) Environmental factors I: which are focused on FW ecological impacts and deriving from FWM performance.

All these factors are invisible factors and not currently considered in KSA-FWM, but have the potential to influence FWM behavior, perceptions and practice in the country.

This stage is very important for qualitative modeling (FCM) of KSA-FWM sustainable development.

#### **3.4.3.2 Fuzzy cognitive mapping (FCM)**

Fuzzy cognitive map is a model of how operating system in terms of defined qualitative variables and the causal relations among these variables. FCM assists the users to decide what the essential factors or variables that might impact the whole system and draws maps to display the causal relationships among system's factors through numbers between  $-1$  and  $1$  (C. Gray, Clark & Jordan, 2012; Özesmi & Özesmi, 2003; Özesmi & Özesmi, 2004).

As mentioned earlier and in section 3.4.3.a, the proposed variables that impact KSA-FWM were identified and grouped into PESTLE indicators before conducting the interviews.

The analysis was performed by using the Mental Modeler software between January and August 2023. It's free, online software at [www.mentalmodeler.org](http://www.mentalmodeler.org), which is created by (Gray, 2012). Each stakeholder (expert) creates one FCM. Then, combine all stakeholder's maps into one big map called Social FCM (Fig 9). The social map is arrived by calculating the average (mean) of the values between components for all individual maps (S. A. Gray, Gray, S., Cox, L. J., & Henly-Shepard, S. , 2013). FCMapper software was also utilized for dynamic analysis and scenarios steady state (s.s) calculations. It is freely platform at [www.fcmappers.net](http://www.fcmappers.net) and created in 2009 by two ecologists Michael Bachhofer and Martin Wildenberg (Papageorgiou, 2013).

In this research, 8 interviews were conducted with stakeholders related to three different stakeholder groups: academic research community (4 members), local retailers (3 members), and recycling company (SRIC) (1 member). In total 8 people (4 men and 4 women).

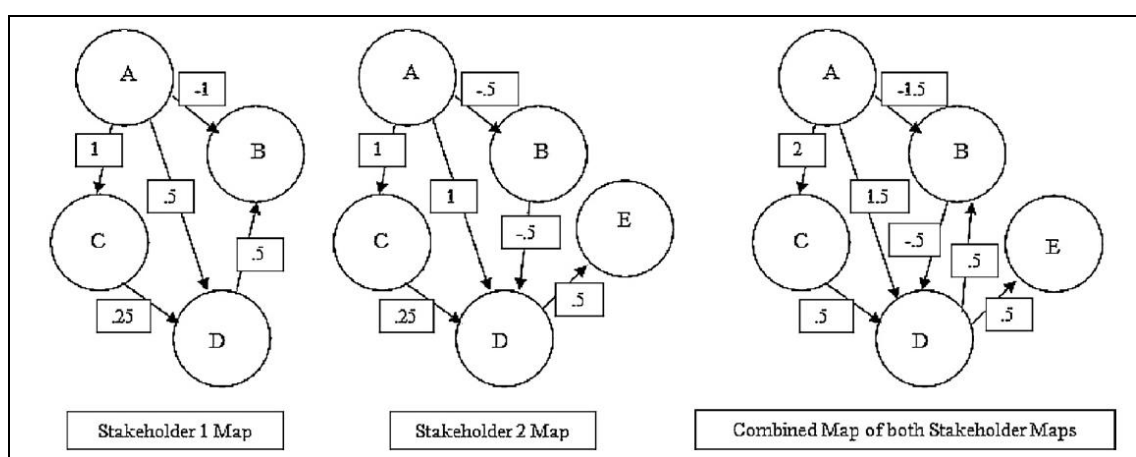


Figure 9: Example of combining stakeholder maps. Source (Gray, 2012)

FCM was implemented to provide an analytical, a participatory approach for a complex system and interactions among factors, and for better understanding to the structural and functional aspects of FWM systems via the causal relationships recognized by relevant stakeholders and experts in the field of KSA-FWM. This phase was applied in three steps as described below and **Figure 10**.

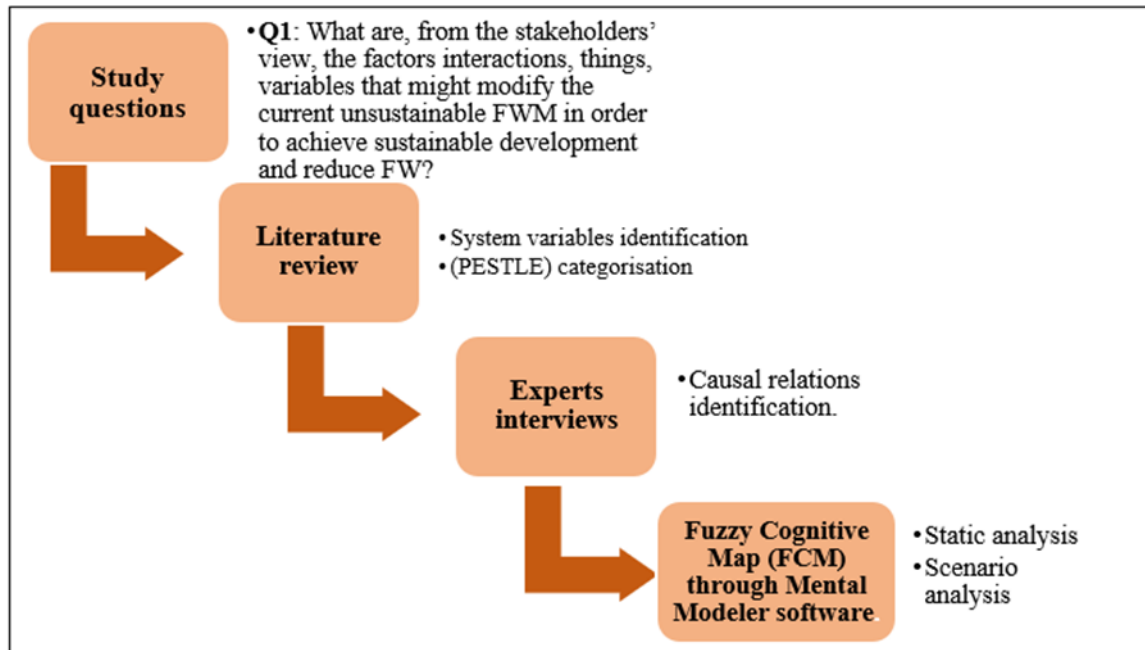


Figure 10:Operational framework of the FCM in this research elaborated by the research author.

### 3.4.3.2.1 Concept Mapping Interface (pairwise comparison)

#### step:

This step is associated with the FCM software (Mental Modeler) platform. This step was performed by asking each participate “What are, from the stakeholders' view, the factors or variables interactions that might modify the current unsustainable FWM in order to achieve sustainable development and reduce FW?”

Each expert expressed their thoughts by drawing directional arrows (called edge relationships) between pairs of variables to elicit causal relationships (S. A. Gray, Zanre, E., & Gray, S. R., 2013). Causal relationships between

variables can be positive, negative or no relationship defined attaching values (weight) of each link regard to stakeholder's perception between -1 (high negative) to 1 (high positive) used for the second step. In addition, there are three types of function variables for each FCM transmitter: ordinary variables and receiver variables. The transmitter variables (force function) are positive output with a zero input and their function is force other variables in the model. In contrast, receiver variables have a positive input degree and a zero output, which does not affect the other variables in the model. Ordinary variables represent both non-zero input and output, extending the effect of simulation on the variables in the model (Bougon, Weick, & Binkhorst, 1977; Nyaki, 2014).

#### **3.4.3.2.2 Matrix Interface step**

It transforms the concept matrix into adjacency matrices (structural characteristics) in form  $I$  (vertical) and  $j$  (horizontal) axes of the FCM. It is considered a matrix algebra calculation. In this step, it is calculated graph theory including several measurements e.g., the number of variable connections, three types of variables (driving variables, receiving variables, and ordinary variables), as well as density, diameter, and complexity measures of each map. It also provides variable level metrics, such as centrality, in-degree, out-degree, and type for each variable.

#### **3.4.3.2.3 Scenario Interface step**

It is an artificial scenario that runs and compares different scenarios based on the causal relationships defined in the first-step concept map interface. The scenarios are presented as a bar graph to reveal how variables might respond under a given scenario (S. A. Gray, Gray, S., Cox, L. J., & Henly-Shepard, S. , 2013). In present research, the simulation question was “How

can the policy actions and green management (composting, recycling, bio-refinery, etc.) support in designing and development the KSA-FWM?

To answer that question the study were run two scenarios: policy actions scenario and green management scenario to provide a clear direction for discussion makers to shape their interferences, and to help stakeholder partnerships for better address FWM priorities and find sustainable solutions.

Table( 4): Objectives aligned with research methods.

|          | <b>Research Objectives</b>                                                                                          | <b>Research Methods</b>                                                                                                                                                                                             |
|----------|---------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>1</b> | Estimate the public awareness about food waste management.                                                          | <ul style="list-style-type: none"> <li>▪ Consumer Survey</li> <li>▪ Descriptive analysis (SPSS)</li> <li>▪ Literature review</li> </ul>                                                                             |
| <b>2</b> | Suggestions and guidelines for implementing recommendations in the future.                                          | <ul style="list-style-type: none"> <li>▪ Retail company questionnaire</li> <li>▪ Categorization analysis</li> <li>▪ food waste management decision tree style (FWMDT)</li> <li>▪ Literature review</li> </ul>       |
| <b>3</b> | Analysis of Saudi's stakeholders sustainable FWM implementation's limits and barriers.                              | <ul style="list-style-type: none"> <li>▪ Stakeholders visit and interview</li> <li>▪ Modeling and simulation/Fuzzy cognitive map (FCM)</li> <li>▪ Static and scenarios analysis</li> </ul>                          |
| <b>4</b> | Minimize environmental impacts of FW by using innovation management practices.                                      | <ul style="list-style-type: none"> <li>▪ Consumer and retail company survey</li> <li>▪ Categorization analysis</li> <li>▪ Food Waste Management Decision Tree style (FWMDT)</li> <li>▪ Literature review</li> </ul> |
| <b>5</b> | Explore stakeholders' perspectives and the role interactions in regard of FWM in the Saudi Arabia (Al Khobar city). | <ul style="list-style-type: none"> <li>▪ Stakeholders visit and interview</li> <li>▪ Modeling and simulation/Fuzzy cognitive map (FCM)</li> <li>▪ Static and scenarios analysis</li> </ul>                          |

### **3.5 Chapter summary**

This chapter has displayed different approaches and methods that have been adopted in this research. This chapter presents the different approaches and methods adopted in this study. These approaches are consistent with their objectives and outcomes and are summarized in the table (Table 4). The methods chapter covers different types of data collection, questionnaires, different indicators and data analysis, and modeling with stimulations. The next chapter presents the results and discussion of the research methodology.

## **CHAPTER 4: Results And Discussion**

### **4.1. Introduction**

This chapter presents the outcomes and findings derived from the research procedures and methodologies outlined in **Chapter 3**. Additionally, it includes a discussion section analysing the findings vis-à-vis the stated aims and objectives outlined in **Chapter 1**.

### **4.2. The research results**

The results are categorized into three main sections. First section is the Food Waste Management Awareness which explores the level of awareness regarding FWM practices. Second section is related to current Food Waste Management Performance in Al Khobar City and assesses in detail the existing performance of food waste management within the context of Al Khobar city. The final section encompasses modelling and simulation presenting the outcomes in this domain providing insights into potential strategies for enhancing FWM practices.

#### **4.2.1. Food waste management awareness**

This section aims to assess public (consumer) awareness, knowledge, and habits towards sustainable FWM and to provide recommendations that can foster behaviour change for managing FW in a sustainable manner. This was achieved through a questionnaire survey conducted among consumers, with subsequent descriptive analysis performed using the SPSS, as detailed in **Section 3.4.1** of the methodology chapter.

##### **4.2.1.1 Socio-demographic characteristics**

The sample of this study comprised 402 respondents. The results showed that 57.7% of respondents were female, and 42.3% were male who

completed the survey. The majority of respondents (57.5%) fell within the age range of 18-25 years. Additionally, a significant proportion of respondents were unmarried (62.9%), students (48%), and held a bachelor's degree (50.7%). In addition, the family size with more than 5 members constituted 56.7% of the respondents, which is relatively large as compared to western norms, and respondents with income levels below 2999 Saudi Riyal (SAR), which is equivalent to \$797.48, were 34.3 % of the sample, as shown in **Table 5**. In this study, most of the respondents were Saudis (61.9%), with the highest percentage of 55.4% (138) coming from Eastern region in KSA followed by 18.5% (46) from the Central region, 12.4% (31) from the Western region, 11.2% (28) from the Southern region, and 2.4% (6) from the Northern part. In contrast, 38.1% were Non-Saudis belonging to 15 countries including Bahrain (41.8%), UAE (2.2%), Kuwait (1.2%), Oman (0.5%), Qatar (0.2%), Egypt (0.7%), Lebanon (1.2%), Jordan (0.7%), Iraq (0.2%), Turkey (0.2%), Malaysia (5%), India (4.7%), Pakistan (0.5%), USA (0.5%), and remaining 4% comprising of various other nationalities.

Table (5): The respondents' socio-demographic characteristics of the consumers' survey.

\* SAR = USD 3.75

| <b>Variables</b>                 | <b>Female</b> | <b>Male</b> | <b>Frequencies</b> | <b>Value %</b>  |
|----------------------------------|---------------|-------------|--------------------|-----------------|
| <b>1) Gender</b>                 | 232           | 170         | 402                | (57.7%) (42.3%) |
| <b>2) Age</b>                    |               |             |                    |                 |
| <b>18-25</b>                     | 176           | 55          | 231                | 57.5%           |
| <b>26-45</b>                     | 46            | 68          | 114                | 28.4%           |
| <b>&gt;45</b>                    | 10            | 47          | 57                 | 14.2%           |
| <b>3) Education level</b>        |               |             |                    |                 |
| <b>Secondary or Diploma</b>      | 71            | 60          | 131                | 32.6%           |
| <b>Bachelor</b>                  | 125           | 79          | 204                | 50.7%           |
| <b>Postgraduate</b>              | 36            | 31          | 67                 | 16.7%           |
| <b>4) Profession</b>             |               |             |                    |                 |
| <b>Student</b>                   | 148           | 45          | 193                | 48%             |
| <b>Employee</b>                  | 41            | 105         | 146                | 36.3%           |
| <b>Freelancer/business owner</b> | 9             | 2           | 11                 | 2.7%            |
| <b>Other</b>                     | 34            | 18          | 52                 | 12.9%           |
| <b>5) Marital status</b>         |               |             |                    |                 |

|                                                   |     |     |     |        |
|---------------------------------------------------|-----|-----|-----|--------|
| <b>Married</b>                                    | 49  | 100 | 149 | 37.1%  |
| <b>Unmarried</b>                                  | 183 | 70  | 253 | 62.9%  |
| <b>6) Number of family members including you.</b> |     |     |     |        |
| <b>1-2</b>                                        | 11  | 16  | 27  | 6.7%   |
| <b>3-5</b>                                        | 84  | 63  | 147 | 36.6%  |
| <b>More than 5</b>                                | 137 | 91  | 228 | 56.7%  |
| <b>7) Monthly Income</b>                          |     |     |     |        |
| <b>&lt; SAR4999</b>                               | 108 | 30  | 138 | 34.3 % |
| <b>SAR 5000-9999</b>                              | 55  | 36  | 91  | 21.9%  |
| <b>SAR 10000-14999</b>                            | 26  | 26  | 52  | 12.9%  |
| <b>&gt; SAR15000</b>                              | 43  | 78  | 121 | 30.1%  |
| <b>8) Nationality</b>                             |     |     |     |        |
| <b>Saudi</b>                                      | 106 | 143 | 249 | 61.9%  |
| <b>Non-Saudi</b>                                  | 126 | 27  | 153 | 38.1%  |

#### 4.2.1.2 Awareness of the consequences and impacts of FW

**Table 6** presents the analysis of the results regarding the respondents' awareness of FW consequences. The majority of respondents exhibited lower scores in terms of consciousness regarding the impact of FW on water (19.7%), carbon (28.6%), and ecological footprints (31.8%), respectively. The study employed a scale ranging from 1 to 5 to capture respondents' perceptions of FW. A value of 1 denoted "not responsible", while a value of 5 signified "extremely responsible", as illustrated in **Table 6**. In contrast, the study confirmed that 89.1% of the respondent's expressed seriousness regarding FW, while 78.1% expressed concerns about its implications for the ecosystem and food security. Additionally, a total of 92% of the respondents indicated their readiness to learn and improve unsustainable behaviour related to food waste, with 56.5% preferring to receive such information through social media channels.

Table( 6): Respondents' awareness regarding the FW impacts.

| <b>Variables</b>                                             | <b>Female</b> | <b>Male</b> | <b>Frequencies</b> | <b>Value %</b> | <b>P-value</b> |
|--------------------------------------------------------------|---------------|-------------|--------------------|----------------|----------------|
| <b>9) Food waste is for the planet</b>                       |               |             |                    |                |                |
| <b>A serious problem</b>                                     | 215           | 143         | 358                | 89.1%          | < .001         |
| <b>A non-serious problem</b>                                 | 17            | 27          | 44                 | 10.9%          |                |
| <b>10) Is the food security an issue of concern for you?</b> |               |             |                    |                |                |

|                                                                                              |     |     |     |       |        |
|----------------------------------------------------------------------------------------------|-----|-----|-----|-------|--------|
| Yes                                                                                          | 183 | 131 | 314 | 78.1% | < .001 |
| No                                                                                           | 49  | 39  | 88  | 21.9% |        |
| 11) Do you know the meaning of water footprint?                                              |     |     |     |       |        |
| Yes                                                                                          | 52  | 27  | 79  | 19.7% | < .001 |
| No                                                                                           | 180 | 143 | 323 | 80.3% |        |
| 12) Do you know the meaning of carbon footprint?                                             |     |     |     |       |        |
| Yes                                                                                          | 70  | 45  | 115 | 28.6% | < .001 |
| No                                                                                           | 162 | 125 | 287 | 71.4% |        |
| 13) Do you know the meaning of ecological footprint?                                         |     |     |     |       |        |
| Yes                                                                                          | 81  | 47  | 128 | 31.8% | < .001 |
| No                                                                                           | 151 | 123 | 274 | 68.2% |        |
| 14) What is the best statement that describes your thoughts on food waste?                   |     |     |     |       |        |
| I think food waste is unavoidable                                                            | 21  | 13  | 34  | 8.5%  | < .001 |
| I've never considered the problem before, but I plan to change my behavior                   | 24  | 12  | 36  | 9%    |        |
| I'm worried about food waste, and I attempt to avoid it                                      | 187 | 145 | 332 | 82.6% |        |
| 15) How responsible do you think yourself towards food waste from 1 to 5?                    |     |     |     |       |        |
| 1 Not responsible                                                                            | 7   | 2   | 9   | 2.2%  | < .001 |
| 2                                                                                            | 12  | 8   | 20  | 5%    |        |
| 3                                                                                            | 50  | 23  | 73  | 18.2% |        |
| 4                                                                                            | 67  | 49  | 116 | 28.9% |        |
| 5 Extremely responsible                                                                      | 96  | 88  | 184 | 45.8% |        |
| 16) What do you think is the best practice to reduce food waste?                             |     |     |     |       |        |
| Reduce food consumption at source                                                            | 38  | 34  | 72  | 17.9% | < .001 |
| Make food more expensive                                                                     | 0   | 2   | 2   | 0.5%  |        |
| Education and awareness                                                                      | 57  | 55  | 112 | 27.9% |        |
| Using Social Media networking                                                                | 3   | 2   | 5   | 1.2%  |        |
| Pay taxes and charges on wasted food                                                         | 26  | 11  | 37  | 9.2%  |        |
| Share or donate food                                                                         | 108 | 66  | 174 | 43.3% |        |
| 17) Would you like to be informed about the consequences of food waste and how to reduce it? |     |     |     |       |        |
| Yes                                                                                          | 218 | 152 | 370 | 92%   | < .001 |
| No                                                                                           | 14  | 18  | 32  | 8%    |        |
| 18) How would you prefer to receive more information?                                        |     |     |     |       |        |
| SMS message                                                                                  | 23  | 35  | 58  | 14.4% | < .001 |
| Mobile app                                                                                   | 27  | 10  | 37  | 9.2%  |        |
| Social Media                                                                                 | 143 | 84  | 227 | 56.5% |        |

|                 |    |    |    |       |
|-----------------|----|----|----|-------|
| <b>E-mail</b>   | 23 | 25 | 48 | 11.9% |
| <b>TV/radio</b> | 16 | 16 | 32 | 8%    |

### 4.2.1.3 Knowledge of the FWM

In terms of the respondents' knowledge of FWM, most of the participants couldn't recognize the disposal destination, as shown in **Table 7**. Based on the majority of participants' response, landfill and incineration were considered ineffective ways to minimize the volume of FW. However, 30.3% of the participants thought that the current FWM method of collecting and managing food waste in their countries is appropriate and eco-friendly, while 44.3% remained undecided. Many of the participants agreed on establishing national FWM plans and legislations that might help to prevent FW in the society. Moreover, 39.3% of the respondents were not supportive of introducing new taxes and charges for supporting FW reduction efforts. The strategy of promoting FW sorting by isolating organic waste from other solid waste (such as plastic and paper) received the highest score of 84.1% in the survey. About 78.6% of the respondents had heard of FW recycling, and 82.8% confirmed that FW can be used as an alternative source of energy and for composting. Additionally, 47.5% of the participants reported that they always used FW to feed the animals. However, 49.8% responded that they never composted FW. Based on these findings, participants' preferred FWM practices were classified into three categories: reduction, reusing, and recycling, as shown in **Table 8**.

Table (7): Respondents' knowledge regarding FWM

| <b>Variables</b>                                                                                                        | <b>Female</b> | <b>Male</b> | <b>Frequencies</b> | <b>Value %</b> | <b>P-value</b> |
|-------------------------------------------------------------------------------------------------------------------------|---------------|-------------|--------------------|----------------|----------------|
| <b>19) Do you know where food waste is taken daily and how it is disposed?</b>                                          |               |             |                    |                |                |
| <b>Yes</b>                                                                                                              | 91            | 59          | 150                | 37.3%          | < .001         |
| <b>Not sure</b>                                                                                                         | 0             | 1           | 0                  | 0%             |                |
| <b>No</b>                                                                                                               | 141           | 110         | 251                | 62.4%          |                |
| <b>20) Sorting food waste away from other solid wastes such as plastic and paper important to take advantage of it.</b> |               |             |                    |                |                |
| <b>Yes</b>                                                                                                              | 199           | 139         | 338                | 84.1%          |                |

|                                                                                                                                        |     |     |     |       |        |
|----------------------------------------------------------------------------------------------------------------------------------------|-----|-----|-----|-------|--------|
| Not sure                                                                                                                               | 28  | 27  | 55  | 13.7% | < .001 |
| No                                                                                                                                     | 5   | 4   | 9   | 2.2%  |        |
| 21) Using the method of landfill or incineration food waste is an effective way to dispose of and reduce the volume of waste.          |     |     |     |       |        |
| Yes                                                                                                                                    | 71  | 35  | 106 | 26.4% | < .001 |
| Not sure                                                                                                                               | 77  | 58  | 135 | 33.6% |        |
| No                                                                                                                                     | 84  | 77  | 161 | 40%   |        |
| 22) I know what you mean by food waste recycling                                                                                       |     |     |     |       |        |
| Yes                                                                                                                                    | 189 | 127 | 316 | 78.6% | < .001 |
| No                                                                                                                                     | 43  | 43  | 86  | 21.4% |        |
| 23) Turning some food leftovers into composting or energy source type of food waste re-cycling                                         |     |     |     |       |        |
| Yes                                                                                                                                    | 195 | 138 | 333 | 82.8% | < .001 |
| Not sure                                                                                                                               | 31  | 23  | 54  | 13.4% |        |
| No                                                                                                                                     | 6   | 9   | 15  | 3.7%  |        |
| 24) Food waste management is important to me.                                                                                          |     |     |     |       |        |
| I agree                                                                                                                                | 213 | 158 | 371 | 92.3% | < .001 |
| Disagree                                                                                                                               | 19  | 12  | 31  | 7.7%  |        |
| 25) I think the current way of collecting and managing food waste is appropriate and eco-friendly.                                     |     |     |     |       |        |
| I agree                                                                                                                                | 76  | 46  | 122 | 30.3% | < .001 |
| Not sure                                                                                                                               | 111 | 67  | 178 | 44.3% |        |
| Disagree                                                                                                                               | 45  | 57  | 102 | 25.4% |        |
| 26) Eco-friendly food waste management contributes to the sustainable development of the country and highlights it in a beautiful way. |     |     |     |       |        |
| I agree                                                                                                                                | 193 | 133 | 326 | 81.1% | < .001 |
| Not sure                                                                                                                               | 34  | 27  | 61  | 15.2% |        |
| Disagree                                                                                                                               | 5   | 10  | 15  | 3.7%  |        |
| 27) Food waste management is a shared responsibility between the individual in society and related institutions                        |     |     |     |       |        |
| I agree                                                                                                                                | 212 | 152 | 364 | 90.5% | < .001 |
| Not sure                                                                                                                               | 17  | 13  | 30  | 7.5%  |        |
| Disagree                                                                                                                               | 3   | 5   | 8   | 2%    |        |
| 28) School education should be used to raise environment awareness about the importance of food waste management in society            |     |     |     |       |        |
| I agree                                                                                                                                | 215 | 161 | 376 | 93.5% | < .001 |
| Not sure                                                                                                                               | 13  | 3   | 16  | 4%    |        |
| Disagree                                                                                                                               | 4   | 6   | 10  | 2.5%  |        |
| 29) Social media networks should be used to spread environment awareness in society about food waste management and food conservation  |     |     |     |       |        |
| I agree                                                                                                                                | 220 | 161 | 381 | 94.8% | < .001 |
| Not sure                                                                                                                               | 6   | 5   | 11  | 2.7%  |        |
| Disagree                                                                                                                               | 6   | 4   | 10  | 2.5%  |        |
| 30) I am with applying National Food Waste Management Plan.                                                                            |     |     |     |       |        |
| I agree                                                                                                                                | 204 | 157 | 361 | 89.8% | < .001 |
| Not sure                                                                                                                               | 23  | 10  | 33  | 8.2%  |        |
| Disagree                                                                                                                               | 5   | 3   | 8   | 2%    |        |
| 31)Do you think there is a need for a system or law to identify violations and penalties to prevent food waste in society?             |     |     |     |       |        |
| I agree                                                                                                                                | 182 | 131 | 313 | 77.9% | < .001 |
| Not sure                                                                                                                               | 36  | 21  | 57  | 14.2% |        |
| Disagree                                                                                                                               | 14  | 18  | 32  | 8%    |        |
| 32) Is it fair to pay fees based on the amount of consumer's food waste generated?                                                     |     |     |     |       |        |

|                                                                                                                                             |     |     |     |       |        |
|---------------------------------------------------------------------------------------------------------------------------------------------|-----|-----|-----|-------|--------|
| I agree                                                                                                                                     | 85  | 62  | 147 | 36.6% | < .001 |
| Not sure                                                                                                                                    | 64  | 33  | 97  | 24.1% |        |
| Disagree                                                                                                                                    | 83  | 75  | 158 | 39.3% |        |
| 33) I am with paying municipal fees for distributing and serving especial smart bins for food waste                                         |     |     |     |       |        |
| I agree                                                                                                                                     | 122 | 73  | 195 | 48.5% | < .001 |
| Not sure                                                                                                                                    | 53  | 29  | 82  | 20.4% |        |
| Disagree                                                                                                                                    | 57  | 68  | 125 | 31.1% |        |
| 34) I think there is a need to provide citizens and residents with special guidelines for the safe and eco-friendly disposal of food waste. |     |     |     |       |        |
| I agree                                                                                                                                     | 220 | 164 | 384 | 95.5% | < .001 |
| Not sure                                                                                                                                    | 10  | 4   | 14  | 3.5%  |        |
| Disagree                                                                                                                                    | 2   | 2   | 4   | 1%    |        |
| 35) I'm ready to separate the food waste at home from other solid wastes in separate bins if the municipal has asked me to do that.         |     |     |     |       |        |
| I agree                                                                                                                                     | 193 | 145 | 338 | 84.1% | < .001 |
| Not sure                                                                                                                                    | 28  | 20  | 48  | 11.9% |        |
| Disagree                                                                                                                                    | 11  | 5   | 16  | 4%    |        |
| 36) I collect food waste for feeding animals (farms and barns).                                                                             |     |     |     |       |        |
| Always                                                                                                                                      | 111 | 80  | 191 | 47.5% | < .001 |
| Sometimes                                                                                                                                   | 100 | 76  | 176 | 43.8% |        |
| Never                                                                                                                                       | 21  | 14  | 35  | 8.7%  |        |
| 37) I collect food waste to turn it into compost for agriculture                                                                            |     |     |     |       |        |
| Always                                                                                                                                      | 45  | 34  | 79  | 19.7% | < .001 |
| Sometimes                                                                                                                                   | 76  | 47  | 123 | 30.6% |        |
| Never                                                                                                                                       | 111 | 89  | 200 | 49.8% |        |

Table (8): Respondents classification upon their desirable FWM

| Reduction Consumers | Reusing Consumers (re-distribution for human consumption) | Recycling Consumers |            |
|---------------------|-----------------------------------------------------------|---------------------|------------|
| 17.9%               | 43.3%                                                     | Animal Feed-ing     | Composting |
|                     |                                                           | 47.5%               | 19.7%      |
|                     |                                                           | 67.2%               |            |

#### 4.2.1.4 Food consumption behavior

When the participants were asked about their habits toward food consumption, 70.4% indicated that they would not purchase food without using shopping list. 40.8% of the participants reported that their food shopping rotates every week, and 30.1% reported it to be once a month, as shown in **Table 9**. Roughly 43% of the respondents stated that they spent an average of 25% of their monthly income on food. Nearly all the respondents could

identify the difference between the food consumed by expiry or best before dates. The study identified the highest proportion of positive consumer attitudes toward leftovers when eating out and emphasized the importance of avoiding discarding good food to reduce household FW. Various reasons for food disposal were explored, with 21.3% of respondents selecting food expiration as a primary reason, followed by keeping packages open for too long (19.9%), and food spoilage (17.9%). These findings are the result of various factors, including consumer shopping frequency, shopping at long intervals leading to the purchase of stocks of unneeded food, household size and lifestyle considerations, as well as the impact of sociocultural factors on food waste behavior.

Table (9): Respondents' behavior regarding to food consumption

| <b>Variables</b>                                                                                                        | <b>Female</b> | <b>Male</b> | <b>Frequencies</b> | <b>Value %</b> | <b>P-value</b> |
|-------------------------------------------------------------------------------------------------------------------------|---------------|-------------|--------------------|----------------|----------------|
| <b>38) How often do you go for grocery shopping?</b>                                                                    |               |             |                    |                |                |
| Everyday                                                                                                                | 13            | 25          | 38                 | 9.5%           | < .001         |
| Once a week                                                                                                             | 88            | 76          | 164                | 40.8%          |                |
| Twice a week                                                                                                            | 44            | 35          | 79                 | 19.7%          |                |
| Once a month                                                                                                            | 87            | 34          | 121                | 30.1%          |                |
| <b>39) How much do you spend on purchasing food monthly?</b>                                                            |               |             |                    |                |                |
| Approximately an average of 75% of my income                                                                            | 29            | 18          | 47                 | 11.7%          | < .001         |
| Approximately an average of 50% of my income                                                                            | 79            | 50          | 129                | 32.1%          |                |
| Approximately an average of 25% of my income                                                                            | 94            | 79          | 173                | 43%            |                |
| Approximately an average of 15% of my income                                                                            | 30            | 23          | 53                 | 13.2%          |                |
| <b>40) Do you use a shopping list at the time of purchase?</b>                                                          |               |             |                    |                |                |
| Yes                                                                                                                     | 163           | 120         | 283                | 70.4%          | < .001         |
| No                                                                                                                      | 69            | 50          | 119                | 29.6%          |                |
| <b>41) Do the food special offers attract you?</b>                                                                      |               |             |                    |                |                |
| Yes                                                                                                                     | 187           | 131         | 318                | 79.1%          | < .001         |
| No                                                                                                                      | 45            | 39          | 84                 | 20.9%          |                |
| <b>42) Do you know the difference between 'to be consumed by Best before date' and 'to be consumed by Expiry date'?</b> |               |             |                    |                |                |
| Yes                                                                                                                     | 186           | 132         | 218                | 79.1%          | < .001         |
| No                                                                                                                      | 46            | 38          | 84                 | 20.9%          |                |
| <b>43) When you eat out, do you take your leftovers with you?</b>                                                       |               |             |                    |                |                |

|                                                                                  |     |     |     |       |        |
|----------------------------------------------------------------------------------|-----|-----|-----|-------|--------|
| Yes                                                                              | 187 | 141 | 328 | 81.6% | < .001 |
| I would like to, but I do not do it                                              | 28  | 19  | 47  | 11.7% |        |
| No                                                                               | 17  | 10  | 27  | 6.7%  |        |
| 44) Do you still discard good food?                                              |     |     |     |       |        |
| Always                                                                           | 20  | 18  | 38  | 9.5%  | < .001 |
| Sometimes                                                                        | 74  | 61  | 135 | 33.6% |        |
| Never                                                                            | 138 | 91  | 229 | 57%   |        |
| 45) What is the reason behind you discard the food? Choose all the possibilities |     |     |     |       |        |
| The food has not been consumed due to its large packaging                        | 45  | 35  | 80  | 19.9% | < .001 |
| Food has gone bad                                                                | 42  | 30  | 72  | 17.9% |        |
| Package has been opened for too long                                             | 36  | 35  | 71  | 17.6% |        |
| Food purchased in excessive quantities                                           | 20  | 9   | 29  | 7.2%  |        |
| The food has expired                                                             | 49  | 37  | 86  | 21.3% |        |
| I did not like the food                                                          | 22  | 13  | 35  | 8.7%  |        |
| Food purchased due to the presence of special offers and not consumed            | 18  | 11  | 29  | 7.2%  |        |

## 4.2.2 Current Al-Khobar city FWM performance

To assess the current performance of FWM in Al-Khobar city, to minimize environmental impacts through the use of innovative management practices, and to make recommendations for improvements in this regard (objectives 2 or 3 and 4), analytical and qualitative research approaches were adopted. The company questionnaires, classification analysis, and Food Waste Management Decision Tree (FWMDT) were used to extract the results as described previously in **Chapter 3**.

### 4.2.2.1 Retailers' survey results

The categorization in this research is based on nine indicators as described and explained in **Chapter 3**. The classification process for FWM and company surveys in this research was implemented across three food retail companies in Al Khobar city. These companies were selected based on

previous contact to schedule meetings, their prominent position in Saudi markets, their size, significant number of clients or consumers, and an anticipated volume of food waste generated by them. The field visit and in-person interview were held in their headquarters in AL Khobar city as described and explained in detail in **Chapter 3 (Section 3.3.1.2)**. **Table 10 & 11** show the results of retailers' management and performance toward FW along with the most appropriate suggested alternative solutions according to FWMDT (Appendix 4 & 5). Additionally, further management possibilities were explored based on the Food Waste Hierarchy (FWH), as depicted in **Figure 6**.

The results displayed that the current AL Khobar city retailer's FWM is conventional management emphasizing on two main FWM practices namely landfilling and handling returned food products. Firstly, landfills are used for the disposal of uneatable FW, which includes unsellable products such as expired, spoiled, damaged, spilled, or poorly processed items like burned food. This uneatable FW should be segregated and classified according to the FWMDT to identify sustainable alternatives for each type of FW. Secondly, returning unsold food to suppliers when it is one month away from its expiration date or packaged incorrectly is considered avoidable FW. This type of FW can be reduced by using appropriate management options, such as redistribution for human consumption (via food banks and charities) and feeding animals under certain conditions. Furthermore, there were limited recycling practices observed in retailer's management, particularly in selected types of FW (such as bread, fruits and vegetables), as indicated in **Table 10 and 11**.

Table (10): The current management of the+ three retailers for (Eatable waste) with the proposed alternative is based on the FWMDT.

| Categorization<br>Nine Indicators      | The type of food waste                                                                                                                                                        |                                                                                                                          |                                                                                                                          |                                                                 |                                                                 |                                                                                              |                                                                                      |
|----------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------|-----------------------------------------------------------------|----------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|
|                                        | Fruit and vegetable                                                                                                                                                           | Canned food                                                                                                              | Eggs and dairy products (not drinks)                                                                                     | Meat, poultry, and fish                                         | Cereals                                                         | Bread                                                                                        | Ready meals                                                                          |
| <b>Edibility</b>                       | Edible                                                                                                                                                                        | Edible                                                                                                                   | Edible                                                                                                                   | Edible                                                          | Edible                                                          | Edible                                                                                       | Edible                                                                               |
| <b>State</b>                           | Eatable                                                                                                                                                                       | Eatable                                                                                                                  | Eatable                                                                                                                  | Eatable                                                         | Eatable                                                         | Eatable                                                                                      | Eatable                                                                              |
| <b>Origin</b>                          | Plant based                                                                                                                                                                   | Plant or Animal based                                                                                                    | Animal based                                                                                                             | Animal based                                                    | Plant based                                                     | Plant based                                                                                  | Plant or Animal based                                                                |
| <b>Complexity</b>                      | Single product                                                                                                                                                                | Single and Mixed for <b>Plant based</b> products only                                                                    | N/A                                                                                                                      | N/A                                                             | Single                                                          | single                                                                                       | Mixed for Plant based only                                                           |
| <b>Animal-product presence</b>         | N/A                                                                                                                                                                           | In contact with or containing meat for <b>animal-based</b> products only                                                 | Animal products                                                                                                          | in contact with or containing meat                              | N/A                                                             | N/A                                                                                          | in contact with or containing meat, animal by products (All 2 categories applicable) |
| <b>Treatment</b>                       | processed                                                                                                                                                                     | Processed                                                                                                                | Processed                                                                                                                | processed                                                       | Processed                                                       | Processed                                                                                    | Processed                                                                            |
| <b>Packaging</b>                       | Unpackaged                                                                                                                                                                    | Packaged                                                                                                                 | Packaged for dairy products<br>Unpackaged for egg                                                                        | Unpackaged                                                      | Unpackaged                                                      | Unpackaged                                                                                   | Packaged                                                                             |
| <b>Packaging biodegradability</b>      | N/A                                                                                                                                                                           | Non-Biodegradable                                                                                                        | Non-Biodegradable                                                                                                        | N/A                                                             | N/A                                                             | N/A                                                                                          | Non-Biodegradable                                                                    |
| <b>Stage of the supply chain</b>       | Non-catering waste                                                                                                                                                            | Non-catering waste                                                                                                       | Non-catering waste                                                                                                       | Non-catering waste                                              | Non-catering waste                                              | Non-catering waste                                                                           | Non-catering waste                                                                   |
| <b>Current treatment or management</b> | <ul style="list-style-type: none"> <li><b>Recycling</b> (Chopped fruit and vegetables &amp; juices production)</li> </ul>                                                     | <ul style="list-style-type: none"> <li><b>Return</b> to suppliers according to agreement for unsold products.</li> </ul> | Return to suppliers according to agreement for unsold products.                                                          | Return to suppliers according to agreement for unsold products  | Return to suppliers according to agreement for unsold products  | Recycling for bread to rusk. Return to suppliers according to agreement for unsold products. | Return to supplier according to agreement                                            |
| <b>For retailer 1</b>                  | <ul style="list-style-type: none"> <li><b>Return</b> to suppliers according to agreement for unsold products.</li> </ul>                                                      |                                                                                                                          |                                                                                                                          |                                                                 |                                                                 |                                                                                              |                                                                                      |
| <b>For retailer 2</b>                  | <ul style="list-style-type: none"> <li><b>Transfer</b> the stock to other branches</li> <li><b>Return</b> to suppliers according to agreement for unsold products.</li> </ul> | <ul style="list-style-type: none"> <li><b>Return</b> to suppliers according to agreement for unsold products.</li> </ul> | Return to suppliers according to agreement for unsold products.                                                          | Return to suppliers according to agreement for unsold products. | Return to suppliers according to agreement for unsold products. | Recycling for bread to rusk. Return to suppliers according to agreement for unsold products. | Not available                                                                        |
| <b>For retailer 3</b>                  | <ul style="list-style-type: none"> <li><b>Return</b> to suppliers according to agreement for unsold products.</li> </ul>                                                      | <ul style="list-style-type: none"> <li><b>Return</b> to suppliers according to agreement for unsold products.</li> </ul> | <ul style="list-style-type: none"> <li><b>Return</b> to suppliers according to agreement for unsold products.</li> </ul> | <ul style="list-style-type: none"> <li><b>Return</b></li> </ul> | <ul style="list-style-type: none"> <li><b>Return</b></li> </ul> | <ul style="list-style-type: none"> <li><b>Return</b></li> </ul>                              | Not available                                                                        |

|                                                 |                                                                                                   |                                                                             |                                                                                                                                                                    |                                                                                                  |                                                                                                                                      |                                                                                                                                    |               |
|-------------------------------------------------|---------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------|---------------|
| <b>Suggested alternative Management (FWMDT)</b> | <ul style="list-style-type: none"> <li>• (RD)</li> <li>• (AF)</li> <li>• (AD)</li> </ul>          | <ul style="list-style-type: none"> <li>• (RD)</li> <li>• (TH-NR)</li> </ul> | <ul style="list-style-type: none"> <li>• (RD) (dairy products)</li> <li>• (AD) (eggs)</li> <li>• in-vessel I (eggs)</li> <li>• (TH-NR) (dairy products)</li> </ul> | <ul style="list-style-type: none"> <li>• (RD)</li> <li>• (AD)</li> <li>• in-ves-sel I</li> </ul> | <ul style="list-style-type: none"> <li>• (RD)</li> <li>• (AF)</li> <li>• (AD)</li> </ul>                                             | (RD) (AF) (AD)                                                                                                                     | (RD) (TH-NR)) |
| <b>Further possibilities (FWH)</b>              | <ul style="list-style-type: none"> <li>• Land spreading</li> <li>• Industrial purposes</li> </ul> | <ul style="list-style-type: none"> <li>• N/A</li> </ul>                     | <ul style="list-style-type: none"> <li>• Industrial purposes</li> <li>• Food stuff production</li> </ul>                                                           | <ul style="list-style-type: none"> <li>• N/A</li> </ul>                                          | <ul style="list-style-type: none"> <li>• Land spreading</li> <li>• Industrial 86river 86</li> <li>• Food stuff production</li> </ul> | <ul style="list-style-type: none"> <li>• Land spreading</li> <li>• Industrial purposes</li> <li>• Food stuff production</li> </ul> | N/A           |

Table (11): The current management of the three retailers for (Uneatable waste) with the proposed alternative is based on the FWMDT.

| Categorization<br>Nine Indicators                                         | The type of food waste                                                                                                                               |                                                                           |                                                                                                                                    |                                                                                            |                                                                                                                              |                                                                                                                   |                                                                                            |
|---------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------|
|                                                                           | Fruit and vegetable                                                                                                                                  | Canned food                                                               | Eggs and dairy products (not drinks)                                                                                               | Meat, poultry, and fish                                                                    | Cereals                                                                                                                      | Bread                                                                                                             | Ready meals                                                                                |
| <b>Edibility</b>                                                          | Edible                                                                                                                                               | Edible                                                                    | Edible                                                                                                                             | Edible                                                                                     | Edible                                                                                                                       | Edible                                                                                                            | Edible                                                                                     |
| <b>State</b>                                                              | Uneatable                                                                                                                                            | Uneatable                                                                 | Uneatable                                                                                                                          | Uneatable                                                                                  | Uneatable for human but eatable for animal                                                                                   | Uneatable for human but eatable for animal                                                                        | Uneatable                                                                                  |
| <b>Origin</b>                                                             | Plant based                                                                                                                                          | Plant or Animal based                                                     | Animal based                                                                                                                       | Animal based                                                                               | Plant based                                                                                                                  | Plant based                                                                                                       | Plant or Animal based                                                                      |
| <b>Complexity</b>                                                         | Single product                                                                                                                                       | Single and Mixed for <b>Plant based</b> products only                     | N/A                                                                                                                                | N/A                                                                                        | Single                                                                                                                       | single                                                                                                            | Mixed for Plant based only                                                                 |
| <b>Animal-product presence</b>                                            | N/A                                                                                                                                                  | In contact with or containing meat for <b>animal-based</b> products only. | Others                                                                                                                             | others                                                                                     | N/A                                                                                                                          | N/A                                                                                                               | Others                                                                                     |
| <b>Treatment</b>                                                          | N/A                                                                                                                                                  | N/A                                                                       | N/A                                                                                                                                | N/A                                                                                        | N/A                                                                                                                          | N/A                                                                                                               | N/A                                                                                        |
| <b>Packaging</b>                                                          | Unpackaged                                                                                                                                           | Packaged                                                                  | <b>Packaged</b> for dairy products<br><b>Unpackaged</b> for egg                                                                    | Unpackaged                                                                                 | N/A                                                                                                                          | N/A                                                                                                               | Could be separated from Package                                                            |
| <b>Packaging biodegradability</b>                                         | N/A                                                                                                                                                  | Non-Biodegradable                                                         | Non-Biodegradable                                                                                                                  | N/A                                                                                        | Non-Biodegradable                                                                                                            | Non-Biodegradable                                                                                                 | Non-Biodegradable                                                                          |
| <b>Stage of the supply chain</b>                                          | Non-catering waste                                                                                                                                   | Non-catering waste                                                        | Non-catering waste                                                                                                                 | Non-catering waste                                                                         | Non-catering waste                                                                                                           | Non-catering waste                                                                                                | Non-catering waste                                                                         |
| <b>Current treatment or management (For all three selected retailers)</b> | <ul style="list-style-type: none"> <li><b>Disposal &amp; landfill</b> for unsellable products (expired, spoiled and damaged, and spilled)</li> </ul> |                                                                           |                                                                                                                                    |                                                                                            |                                                                                                                              |                                                                                                                   |                                                                                            |
| <b>Suggested alternative Management (FWMDT)</b>                           | <ul style="list-style-type: none"> <li>(AD)</li> <li>I</li> <li>(TH-NR)</li> </ul>                                                                   | <ul style="list-style-type: none"> <li>(TH-NR)</li> </ul>                 | <ul style="list-style-type: none"> <li>AD (eggs)</li> <li>in-vessel I (eggs)</li> <li>(TH-NR) (eggs and dairy products)</li> </ul> | <ul style="list-style-type: none"> <li>AD</li> <li>in-vessel I</li> <li>(TH-NR)</li> </ul> | <ul style="list-style-type: none"> <li>(AF)</li> <li>(AD)</li> <li>I</li> </ul>                                              | <ul style="list-style-type: none"> <li>(AF)</li> <li>(AD)</li> <li>I</li> </ul>                                   | <ul style="list-style-type: none"> <li>AD</li> <li>in-vessel I</li> <li>(TH-NR)</li> </ul> |
| <b>Further possibilities (FWH)</b>                                        | <ul style="list-style-type: none"> <li>Land spreading</li> <li>Industrial purposes</li> </ul>                                                        | <ul style="list-style-type: none"> <li>N/A</li> </ul>                     | <ul style="list-style-type: none"> <li>Industrial purposes</li> <li>Food stuff production</li> </ul>                               | <ul style="list-style-type: none"> <li><b>N/A</b></li> </ul>                               | <ul style="list-style-type: none"> <li>Land spreading</li> <li>Industrial purposes</li> <li>food stuff Production</li> </ul> | <ul style="list-style-type: none"> <li>Land spreading</li> <li>Industrial purposes</li> <li>Production</li> </ul> | <ul style="list-style-type: none"> <li><b>N/A</b></li> </ul>                               |

|                                                                                                      |             |            |            |             |             |                     |             |
|------------------------------------------------------------------------------------------------------|-------------|------------|------------|-------------|-------------|---------------------|-------------|
|                                                                                                      |             |            |            |             |             | of<br>food<br>stuff |             |
| <b>Average total<br/>quantity (Re-<br/>tailer1)<br/>For both eatable<br/>and uneatable<br/>waste</b> | 800 MT/year | 90 MT/year | 185MT/year | 365 MT/year | 110 MT/year | 275<br>MT/year      | 450 MT/year |
| <b>Average total<br/>quantity (Re-<br/>tailer2)<br/>For both eatable<br/>and uneatable<br/>waste</b> | N/A         | N/A        | N/A        | N/A         | N/A         | N/A                 | N/A         |
| <b>Average total<br/>quantity (Re-<br/>tailer3)<br/>For both eatable<br/>and uneatable<br/>waste</b> | N/A         | N/A        | N/A        | N/A         | N/A         | N/A                 | N/A         |

\* (MT) means ‘metric tons’

\* (N/A) means ‘not applicable’ or ‘that the information is not necessary’

\* (RD) means ‘redistribution’, (AF) ‘animal feeding’, (AD) ‘anaerobic digestion’, I ‘com-posting’ and (TH-NR) ‘thermal treatment with energy recovery’.

#### 4.2.2.2 Analysis of retailers' interviews

This section shows the results of in-person interviews and site visits which were held with retailers' workforce: the Head of Demand Planning of retailer 1 (Tamimi hypermarket), Branch Manager of retailer 2 (Danube hypermarket), and the owner of retailer 3 (Convenience store). In addition, further email contacts were collected for additional information from Operations and Quality Assurance departments. Insights obtained from key interviews revealed the following points:

- The average total quantity of each type of FW (eatable and uneatable waste) by retailers is shown in **Table 11**. However, retailers were discreet in sharing their FW quantity, for example, retailers 2 and 3 did not provide us with a direct amount of its FW quantity and refused to answer this question in the questionnaire.
- The quantity of total FW generated by retailers was found to be linked to the levels and the numbers of consumers who visit the hypermarket, as well as extraordinary events such as the Shaban and Ramadan months.
- In daily retail management methods and logistics, retail store's staff re-examine and re-sort food items to select high-quality products as part of the quality assurance process. At this stage, the retail staff avoids and removes food products that are damaged due to warm weather, bad packaging, improper storage, and defect in cooling tracks during distribution and transportation. Afterwards, the food is placed on store shelves and monitored back and forth by store employees to remove unsold products and regroup them on offered shelves at very low prices or in the form of buy one get one free

offer. At the end of the day, all unsaleable FW goes to the backdoor store or warehouse for transport and disposal in the municipal dump.

- Quality assurance (QA) is an important term for the food industry, ensuring that food products meet consumer's expectations. In this regard, retailer 2 has established "Would You Buy it" (WYB) strategy. It is a marketing technique that aims to remove unwanted or imperfect food that might affect purchase intentions of consumers, such as fruits or vegetables with abnormal shapes, without compromising their nutritional value. Furthermore, transporting some food products (fruits and vegetables) from far distance cities e.g., Qassim and Buraidah to provide great goods is another side of quality assurance process in AL Khobar's retailers. This action could elevate the store's standard in the client's eyes fostering trust. However, empirical evidence suggests that it leads to an increase in the production of FW (Loebnitz, 2015; Stöckli, 2021).
- The selected retailer's management practices (landfilling and returning to suppliers) underscore a prioritization of economic considerations over FW control, notwithstanding the environmental burdens associated with their management approaches. Therefore, it is incumbent upon the retailer's management to conduct a thorough investigation and analysis of the factors contributing to their FW generation and to evaluate their specific cases accordingly.
- The predominant practice in retail management involves returning surplus FW to suppliers, often with uncertain outcomes. This applies particularly to edible, untouched, or unsold food items with expiration dates ranging from one to two months, as detailed in **Table 10**. Further scrutiny and categorization are essential in addressing this issue, a need underscored by the alternative management framework

(FWMDT) and additional avenues proposed in this study (**Tables 10 and 11**).

- The FW sorting and segregation behaviour is non-existent in the retailer's management practices.
- Government policy and legislation are an important part of the process that encourages FWM within retail sector to achieve sustainable development (Davies, 2007). However, the retail sector of KSA lacks adequate government policies to change the quality in FWM practices and minimizing FW generation. The government intervention is crucial in supporting the retail sector (Mukherjee, 2011) by formulating strict legislations with a comprehensive directive at the retailing level to provide continued regulatory provisions for all stakeholders within the country's food industry.
- Providing a defined quality standard to food suppliers can contribute to reducing the FW and financial loss within the retail sector. It also enables the suppliers to search other ways to sell their products rather than accumulating waste, thereby enhancing their incomes (Ismael, 2023).
- The retailers stated that stakeholders on the upstream side (food source), such as farmers, manufacturer, and third parties including waste collectors and municipal authorities are responsible for mis-managing and extracting value from wasted food.

#### **4.2.3 Modelling and simulation analysis results**

This section involves the results of Fuzzy Cognitive Maps (FCMs) and their scenarios. It is divided into three sections as shown below.

#### **4.2.3.1 Variables identification and causal relations of the model**

In this research, there are 19 factors that influence the KSA-FWM identified as a result of a text mining of investigating about variables through a comprehensive literature review as described in **Chapter 3**. These 19 factors (variables) were identified and categorized into a grid of (PESTLE) factors encompassing Political, Economic, Social, Technology, Legal, and Environmental dimensions. **Table 12** provides a brief overview of these factors. In each PESTLE group, there are differences in the numbers of variables. This PESTLE-based classification provides the infrastructure for developing.

In this research, 8 members participated from three different stakeholder groups (**Table 13**). They shared their perspectives and affairs on the current KSA-FWM. Each member constructed an individual map to identify causal relationships between variables and combined the individual cognitive maps into a social cognitive map, as described in **Chapter 3**.

Table( 12): The key FWM factors in KSA via PESTLE category. Source: Constructed by the author.

| ID        | Variables                                                     | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|-----------|---------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|           | <b>Political factors (P)</b>                                  | Which is highlighted the government intervenes, policies and laws that could affect KSA-FWM.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| <b>P1</b> | Government food waste policies and laws.                      | Establish and impose FW rules, policies regulating, and power which can control FWM processes and practices on retailer's actions and consumption behaviours (e.g., enforce policy sorting and segregation food waste at source, adopting reversal approach of waste management that focuses on sources reduction (Prevention) as first stage and landfilling as last stage in food waste treatment, municipal tax services, and food waste tax for tax levied to ensure that food waste disposal is priced to reflect its environmental cost and to reduce food waste volume. |
| <b>P2</b> | Collaboration                                                 | Promotion of cooperation among national food stakeholders (public and private sectors), throughout training, knowledge transfer, networking and management. Also, encourage R&D cooperation,                                                                                                                                                                                                                                                                                                                                                                                   |
| <b>P3</b> | Public investment in infrastructure                           | Funding and infrastructural subsidies a new eco- friendly factory for bio-refineries and by-products to reduce food waste and it's emissions, and to improve inventory management at retail level.                                                                                                                                                                                                                                                                                                                                                                             |
| <b>P4</b> | Information campaigns                                         | Encourage practices and campaigns to increase consumers' awareness of the value of food waste as a resource, if sustainably managed.                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|           | <b>Economic I</b>                                             | which is highlighted essential points that influence sustainable KSA-FWM from an economic perspective                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| <b>C1</b> | Circular economy                                              | Support circular bioeconomy to generate economic value of food waste                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| <b>C2</b> | Green management (recycling, composting, biorefinery.....etc) | Change of some food business sectors to promote greener and sustainable FW management and alternatives e.g., composting, biorefinery, value added products, and offering program or tax incentives for encouraging agro-industrial operators and small-scale farming to donate food surpluses with a good state of conservation. It is also, enhancing sustainable harvest, postharvest management towards food waste reduction.                                                                                                                                               |
| <b>C3</b> | Supply chain efficiency                                       | Integration management of all supply chain roles to manage complexity in the demand and supply of food.                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| <b>C4</b> | Economic growth                                               | Potential income from recycling food waste and taxes                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|           | <b>Social (S)</b>                                             | Which highlighted essential points that influence sustainable KSA-FWM from a social perspective.                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| <b>S1</b> | Public awareness                                              | Related to the socio-economic, environmental and health impacts of mismanagement food waste. It is also participating individuals in recycling programs, food donation and bank, and composting at the urban level as best practice food waste reduction.                                                                                                                                                                                                                                                                                                                      |
| <b>S2</b> | Job opportunities                                             | Create a new job opportunity in labor market in the field of sustainable food waste management.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|           | <b>Technological (T)</b>                                      | which reflected innovative managements that possibly affecting KSA-FWM development.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| <b>T1</b> | IOT knowledge                                                 | Knowledge-based Internet of Things for food waste handling and dumping systems enabling efficiency and improved environmental protection (e.g., smart bins food waste collection, sorting the waste at source, route optimization, etc.).                                                                                                                                                                                                                                                                                                                                      |
| <b>T2</b> | Bio-based industry availabilities                             | Adequate number of facilities are developed technological products and process.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| <b>T3</b> | Research and Development (R&D) activities                     | New innovative research that shifts the utilization, performance, management and practice to develop alternative bio-based materials that could be better recycled or composted                                                                                                                                                                                                                                                                                                                                                                                                |

|           |                                    |                                                                                                                                                                                                                                        |
|-----------|------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|           | <b>Legal (L)</b>                   | Which are stakeholder's responsibilities to comply food waste management guidelines.                                                                                                                                                   |
| <b>L1</b> | Relevant FWM laws and regulations  | Compliance and enforcement of the food political laws towards environmental, economic social considerations.                                                                                                                           |
| <b>L2</b> | International directives           | Follow and comply the environmental guidelines that drafted by international organizations to create uniformity in actions e.g., Food and Agriculture Organization (FAO), The Commission on Sustainable Agriculture and Climate Change |
|           | <b>Environmental I</b>             | Which focused on FW ecological impacts and deriving from FWM performance.                                                                                                                                                              |
| <b>E1</b> | Natural resource use.              | Inefficient utilizing of natural resources and materials (water and energy)                                                                                                                                                            |
| <b>E2</b> | Land degradation and contamination | Land pollution, through the degradation and contamination of the soil and underground water.                                                                                                                                           |
| <b>E3</b> | Climate change                     | Urban air pollution generated from improper and inadequate disposal practices e.g., dumping in landfills, and waste incineration which increase green gas houses.                                                                      |
| <b>E4</b> | Food security                      | Mismanagement of food waste that cause agricultural pressure threaten quality of life and health.                                                                                                                                      |

Table (13): Stakeholders and participants for construction of fuzzy cognitive maps.  
Source: researcher's elaboration.

| Participant | Stakeholder categories                 | Gender | Role                                                | Area of involvement                                               |
|-------------|----------------------------------------|--------|-----------------------------------------------------|-------------------------------------------------------------------|
| Expert 1    | Academia                               | Female | Assistant Professor at King Faisal University (KFU) | Food security/Agricultural business administration                |
| Expert 2    | Academia                               | Female | Assistant Professor at King Faisal University (KFU) | Food security/Agricultural business administration                |
| Expert 3    | Academia                               | Female | Associate Professor (KFU)                           | Agribusiness and consumer sciences/ Agricultural and food science |
| Expert 4    | Academia                               | Male   | Associate Professor (KFU)                           | Agribusiness and consumer sciences/ Agricultural and food science |
| Expert 5    | Food retailing sector (private sector) | Male   | Head of Demand Planning                             | Retail /Demand sector in Tamimi Market                            |
| Expert 6    | Food retailing sector (private sector) | Male   | Branch Manager                                      | Operation department in Danube market                             |
| Expert 7    | Food retailing sector (private sector) | Male   | Manager                                             | Operation department in Convenience store                         |
| Expert 8    | Government official                    | Female | Research and Development Specialist                 | Saudi Investment Recycling Company (SRIC)                         |

#### 4.2.3.2 Results of FCM

This section employed the Mental Modeler as a computational program as the first step in analysing the FCMs' results from expert interviews. It involved describing and organizing the values of the adjacency matrix and their interpretations, as presented in (Appendix 6). These values and their indications were assessed through auto-calculate of the program's software to evaluate and compare various types of stakeholders and to determine the most influential factors on the system based on stakeholders' perspectives.

After aggregating each individual maps of the stakeholders into three stakeholder group maps (Academia group, Retailing group, and Recycling group), a comparison was made among their values, structures, and static features of the FCM network. This comparison displayed the differences in the stakeholders' perspectives and knowledge of FWM (**Table 14** and **15**). The matrix form of individual, group and social FCM networks is shown in (Appendices 7-18).

Table (14): FCM network structure of individual cognitive maps for each stakeholder

| Stakeholder Member | Number of maps for each stakeholder | Total Variables | Total FCM Connections | Connections per Variable (C/N) | Variable Type |           |          | FCM Density | FCM Complexity Score (receiver/driver) |
|--------------------|-------------------------------------|-----------------|-----------------------|--------------------------------|---------------|-----------|----------|-------------|----------------------------------------|
|                    |                                     |                 |                       |                                | 97rive r      | Receivers | Ordinary |             |                                        |
| Expert 1           | 1                                   | 19              | 55                    | 2.89                           | 3             | 1         | 15       | 0.160       | 0.3                                    |
| Expert 2           | 1                                   | 19              | 28                    | 1.47                           | 1             | 11        | 7        | 0.081       | 11                                     |
| Expert 3           | 1                                   | 19              | 69                    | 3.63                           | 1             | 3         | 15       | 0.201       | 3                                      |
| Expert 4           | 1                                   | 19              | 33                    | 1.73                           | 3             | 9         | 7        | 0.096       | 3                                      |
| Expert 5           | 1                                   | 19              | 16                    | 0.84                           | 3             | 9         | 5        | 0.046       | 3                                      |
| Expert 6           | 1                                   | 19              | 17                    | 0.89                           | 7             | 6         | 4        | 0.049       | 0.85                                   |
| Expert 7           | 1                                   | 19              | 17                    | 0.89                           | 5             | 9         | 5        | 0.049       | 1.8                                    |
| Expert 8           | 1                                   | 19              | 34                    | 1.78                           | 2             | 3         | 14       | 0.099       | 1.5                                    |

Table (15): FCM network structure of stakeholder groups and social cognitive maps for KSA-FWM

| Stakeholder group   | Number of maps for each stakeholder group | Total Variables | Total FCM Connections | Connections per Variable (C/N) | Variable Type |           |          | FCM Density (C/N <sup>2</sup> ) | FCM Complexity Score |
|---------------------|-------------------------------------------|-----------------|-----------------------|--------------------------------|---------------|-----------|----------|---------------------------------|----------------------|
|                     |                                           |                 |                       |                                | drivers       | Receivers | Ordinary |                                 |                      |
| Academia Group      | 4                                         | 19              | 125                   | 6.6                            | 0             | 1         | 18       | 0.365                           | infinity             |
| Retailing Group     | 3                                         | 19              | 37                    | 1.9                            | 3             | 4         | 12       | 0.108                           | 1.3                  |
| Government official | 1                                         | 19              | 34                    | 1.8                            | 2             | 3         | 14       | 0.099                           | 1.5                  |
| Social map          | 8                                         | 19              | 160                   | 8.4                            | 0             | 0         | 19       | 0.467                           | 0                    |

\* Density involves the number of variables (N) and the number of connections I of the map.

#### 4.2.3.2.1 FCM of academia group

The results for this group indicated that the academic map has a high potential and is able to adapt to changes within the system to improve KSA-FWM since it has the highest density value compared to the other groups in this study (**Table 14**). FCM of academia group displayed the highest number of connections, connections per variable (C/N), and ordinary factors among all the group maps. Ordinary factors indicated the greatest interactions between the factors of the system, thereby spreading the influences throughout the entire system. While food security was the sole receiving variable with zero driving (transmitting) variable. Academia group map is considered a complex map (**Figure 11**) because the connections between variables and the complexity scores in the individual maps are higher than the other groups.

Government policies and laws, followed by Green management, R&D, Food security, Economic growth, and Collaboration emerge as the most important factors and components for the KSA-FWM system regarding the scientists' perspective due to their higher centrality values in the Mental Modeler system (**Figure 12**). **Figures 13, 14, and 15** show individual FCMs collected from 4 academic members along with their static results.

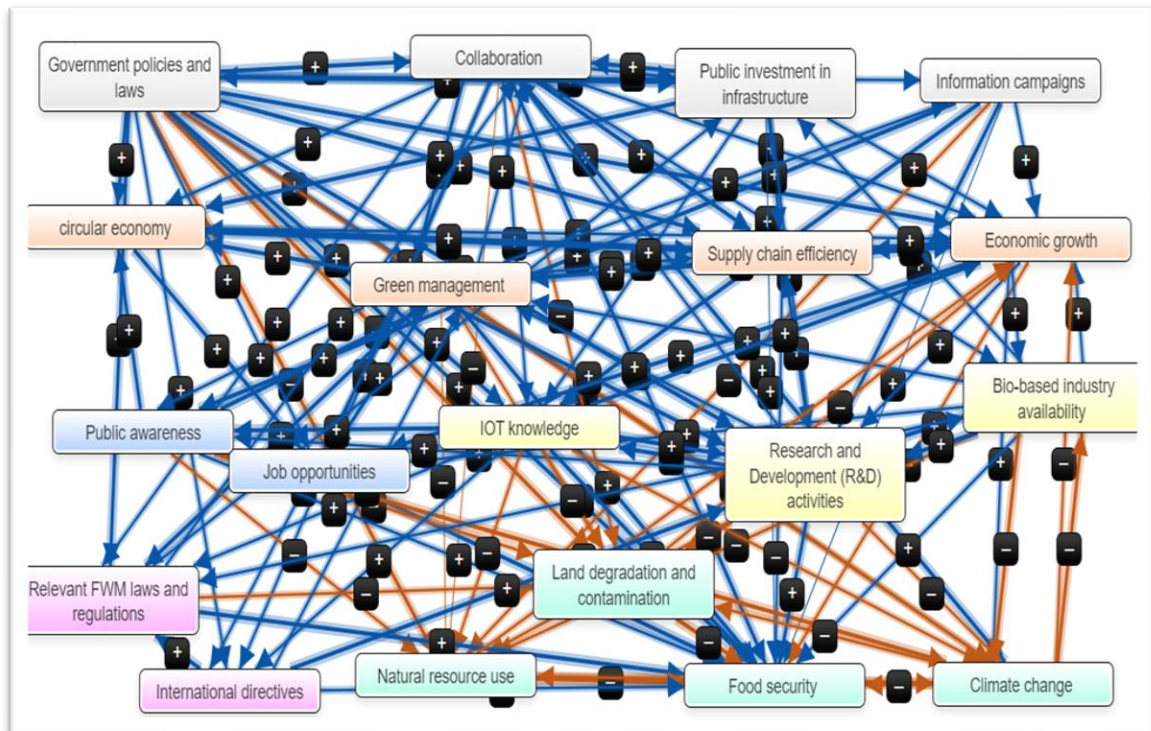
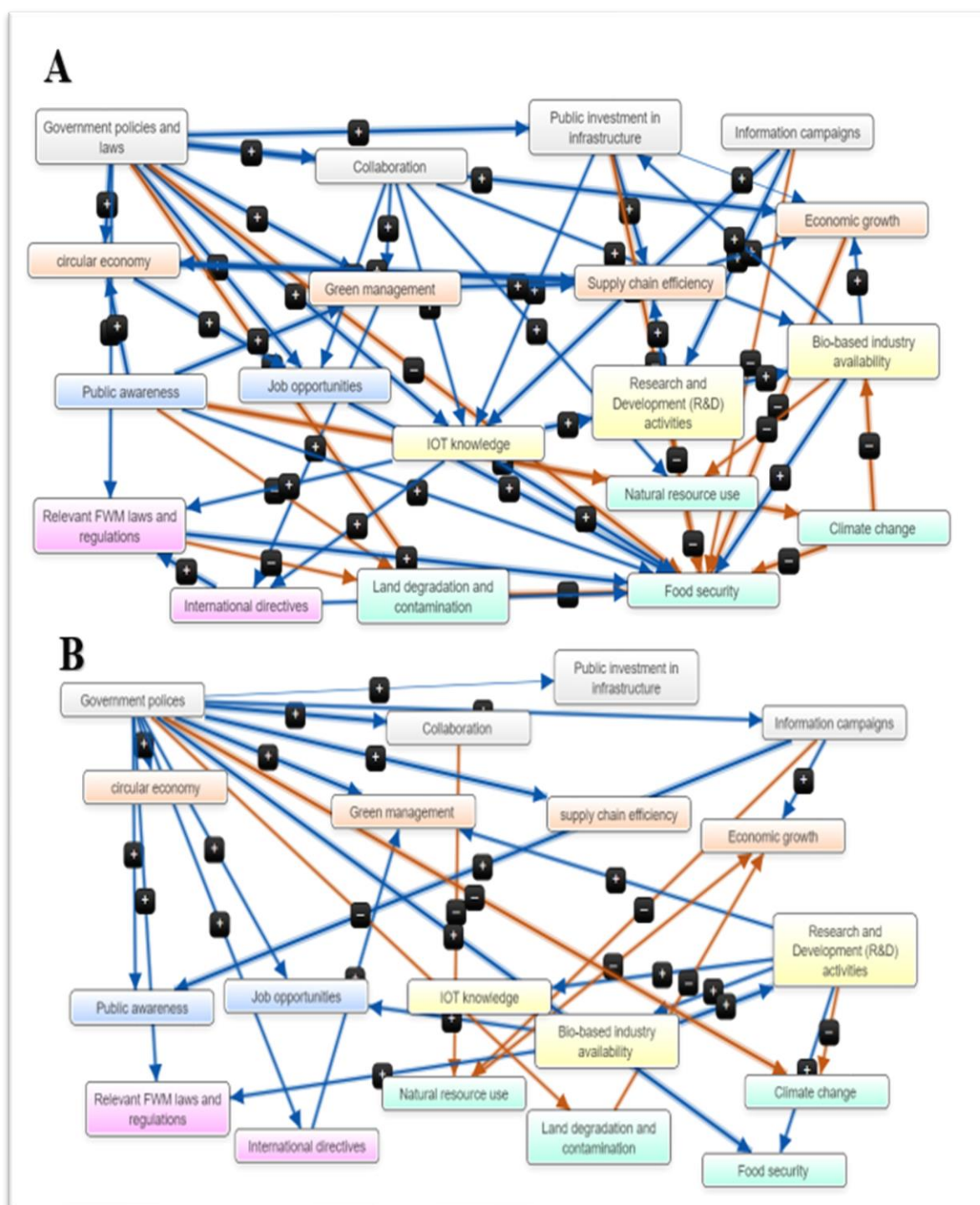


Figure 11: The FCM of academia group of FWM, including all positive (blue) and negative (red) relationships between 19 variables.

| Component                                 | Indegree           | Outdegree          | Centrality         |
|-------------------------------------------|--------------------|--------------------|--------------------|
| Government policies and laws              | 0.76               | 8.380000000000003  | 9.140000000000002  |
| Collaboration                             | 2.07               | 5.700000000000001  | 7.770000000000001  |
| Information campaigns                     | 0.61               | 2.72               | 3.33               |
| Public investment in infrastructure       | 1.48               | 3.750000000000004  | 5.23               |
| circular economy                          | 3.39               | 1.56               | 4.95               |
| Green management                          | 3.1100000000000003 | 5.95               | 9.06               |
| Supply chain efficiency                   | 3.88               | 1.93               | 5.81               |
| Economic growth                           | 5.38               | 2.42               | 7.8                |
| Job opportunities                         | 3.3800000000000003 | 0.5                | 3.8800000000000003 |
| Public awareness                          | 2.1                | 2.7800000000000002 | 4.880000000000001  |
| Research and Development (R&D) activities | 4.08               | 4.46               | 8.54               |
| Bio-based industry availability           | 1.7000000000000002 | 3.43               | 5.130000000000001  |
| IOT knowledge                             | 2.46               | 4.369999999999999  | 6.829999999999999  |
| Relevant FWM laws and regulations         | 2.7                | 1.5799999999999998 | 4.28               |
| Land degradation and contamination        | 3.1000000000000005 | 0.95               | 4.050000000000001  |
| Natural resource use                      | 2.8799999999999994 | 1.46               | 4.34               |
| Food security                             | 7.8900000000000015 | 0                  | 7.8900000000000015 |
| Climate change                            | 3.54               | 2.17               | 5.71               |
| International directives                  | 1.52               | 1.9200000000000002 | 3.4400000000000004 |

Figure 12: Results of the network analysis for FCM of academia group



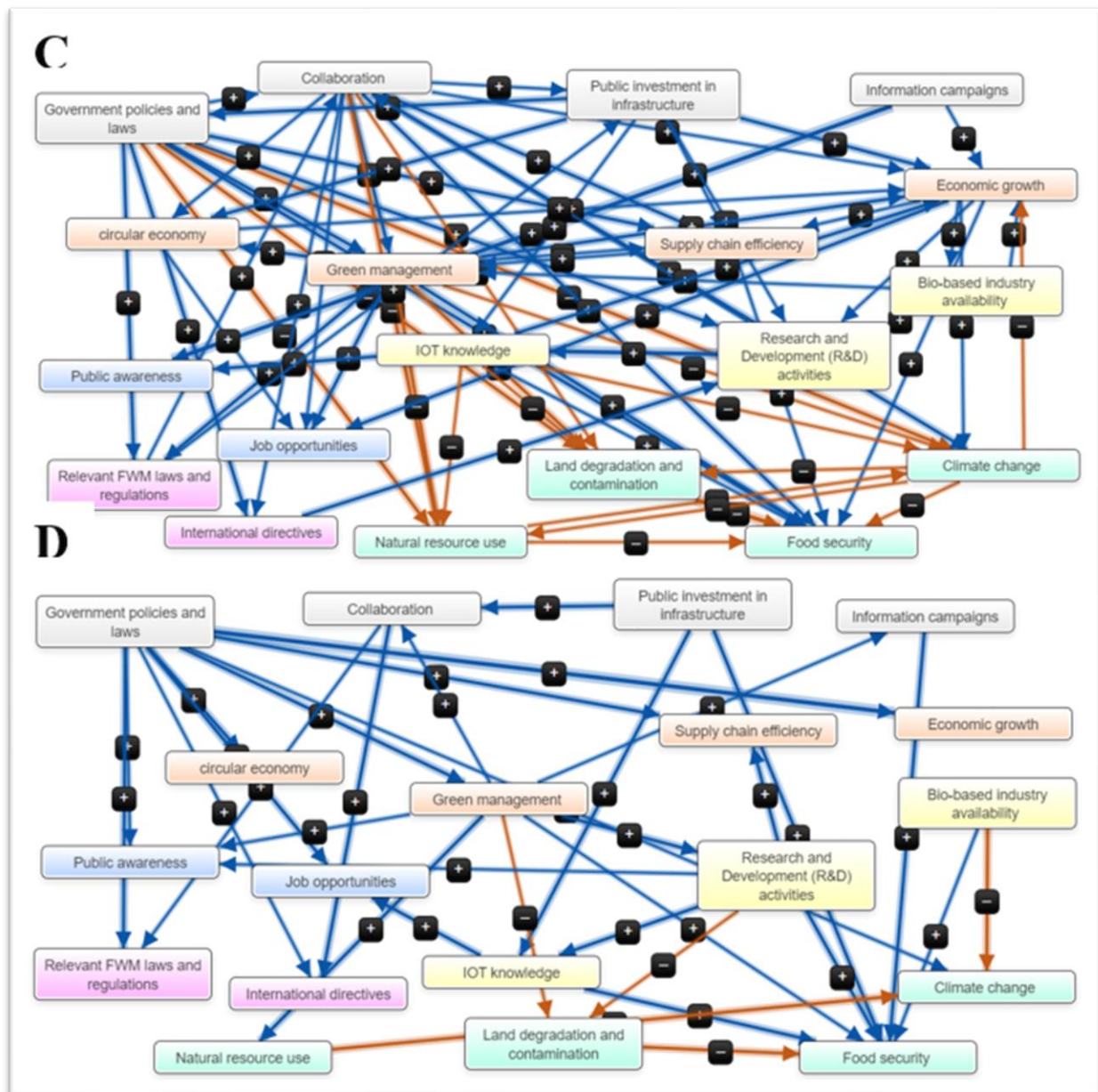


Figure 13 (a,b,c,d):individual FCMs collected from 4 academic members

| <b>A</b> | Component                                 | Indegree           | Outdegree          | Centrality         |
|----------|-------------------------------------------|--------------------|--------------------|--------------------|
|          | Government policies and laws              | 0                  | 5.95               | 5.95               |
|          | Collaboration                             | 0.5                | 1.8599999999999999 | 2.36               |
|          | Information campaigns                     | 0                  | 1.55               | 1.55               |
|          | Public investment in infrastructure       | 1.1                | 1.73               | 2.83               |
|          | circular economy                          | 1.77               | 1.28               | 3.05               |
|          | Green management                          | 1.5299999999999998 | 1.02               | 2.55               |
|          | Supply chain efficiency                   | 2.5700000000000003 | 1.02               | 3.5900000000000003 |
|          | Economic growth                           | 1.5999999999999999 | 0.65               | 2.25               |
|          | Job opportunities                         | 1.55               | 0.5                | 2.05               |
|          | Public awareness                          | 0                  | 2.78               | 2.78               |
|          | Research and Development (R&D) activities | 1.12               | 1.54               | 2.66               |
|          | Bio-based industry availability           | 1.4                | 1.6199999999999999 | 3.0199999999999996 |
|          | IOT knowledge                             | 1.8399999999999999 | 1.84               | 3.6799999999999997 |
|          | Relevant FWM laws and regulations         | 1.46               | 0.9099999999999999 | 2.37               |
|          | Land degradation and contamination        | 1.44               | 0.68               | 2.12               |
|          | Natural resource use                      | 1.6300000000000001 | 0.6                | 2.23               |
|          | Food security                             | 6.81               | 0                  | 6.81               |
|          | Climate change                            | 0.5                | 1                  | 1.5                |
|          | International directives                  | 0.8                | 1.0899999999999999 | 1.89               |
| <b>B</b> | Component                                 | Indegree           | Outdegree          | Centrality         |
|          | Government polices                        | 0                  | 5.300000000000001  | 5.300000000000001  |
|          | Research and Development (R&D) activities | 0.5                | 1.7                | 2.2                |
|          | Information campaigns                     | 0.41               | 1.44               | 1.8499999999999999 |
|          | Bio-based industry availability           | 0.36               | 1.01               | 1.37               |
|          | Green management                          | 1.3                | 0                  | 1.3                |
|          | Public awareness                          | 1.15               | 0                  | 1.15               |
|          | Food security                             | 1.06               | 0                  | 1.06               |
|          | Natural resource use                      | 0.61               | 0.39               | 1                  |
|          | Economic growth                           | 0.99               | 0                  | 0.99               |
|          | Collaboration                             | 0.7                | 0.24               | 0.94               |
|          | Climate change                            | 0.76               | 0                  | 0.76               |
|          | Job opportunities                         | 0.61               | 0                  | 0.61               |
|          | Land degradation and contamination        | 0.32               | 0.25               | 0.5700000000000001 |
|          | International directives                  | 0.2                | 0.33               | 0.53               |
|          | supply chain efficiency                   | 0.5                | 0                  | 0.5                |
|          | Relevant FWM laws and regulations         | 0.45               | 0                  | 0.45               |
|          | circular economy                          | 0.38               | 0                  | 0.38               |
|          | IOT knowledge                             | 0.34               | 0                  | 0.34               |
|          | Public investment in infrastructure       | 0.02               | 0                  | 0.02               |

Figure 14:Results of the network analysis for FCM of academic members (part 1)

| <b>C</b> | Component ▼                               | Indegree ▼         | Outdegree ▼        | Centrality ☉       |
|----------|-------------------------------------------|--------------------|--------------------|--------------------|
|          | Green management                          | 1.88               | 5.639999999999999  | 7.519999999999999  |
|          | Government policies and laws              | 0.76               | 5.829999999999999  | 6.589999999999999  |
|          | Collaboration                             | 1.24               | 5.039999999999999  | 6.279999999999999  |
|          | Economic growth                           | 3.7900000000000005 | 2.3499999999999996 | 6.140000000000001  |
|          | Food security                             | 5.16               | 0                  | 5.16               |
|          | Climate change                            | 2.58               | 1.66               | 4.24               |
|          | Research and Development (R&D) activities | 1.96               | 1.98               | 3.94               |
|          | Public investment in infrastructure       | 0.72               | 3.13               | 3.8499999999999996 |
|          | IOT knowledge                             | 1.25               | 2.5                | 3.75               |
|          | Supply chain efficiency                   | 2.41               | 0.91               | 3.3200000000000003 |
|          | Land degradation and contamination        | 2.46               | 0.84               | 3.3                |
|          | Natural resource use                      | 2.27               | 0.95               | 3.2199999999999998 |
|          | circular economy                          | 1.79               | 0.84               | 2.63               |
|          | Job opportunities                         | 2.06               | 0                  | 2.06               |
|          | Relevant FWM laws and regulations         | 1.2                | 0.6699999999999999 | 1.8699999999999999 |
|          | Bio-based industry availability           | 0.99               | 0.77               | 1.76               |
|          | Public awareness                          | 1.5899999999999999 | 0                  | 1.5899999999999999 |
|          | International directives                  | 0.8300000000000001 | 0.5                | 1.33               |
|          | Information campaigns                     | 0                  | 1.33               | 1.33               |
| <b>D</b> | Component ▼                               | Indegree ▼         | Outdegree ▼        | Centrality ☉       |
|          | Government policies and laws              | 0                  | 5                  | 5                  |
|          | Food security                             | 4                  | 0                  | 4                  |
|          | Research and Development (R&D) activities | 0.5                | 2.54               | 3.04               |
|          | Green management                          | 0.5                | 2.4400000000000004 | 2.9400000000000004 |
|          | IOT knowledge                             | 1.1                | 1.1                | 2.2                |
|          | Public investment in infrastructure       | 0                  | 1.9000000000000001 | 1.9000000000000001 |
|          | Collaboration                             | 0.7                | 1                  | 1.7                |
|          | Land degradation and contamination        | 0.88               | 0.5                | 1.48               |
|          | Climate change                            | 1.4                | 0                  | 1.4                |
|          | Supply chain efficiency                   | 1.3                | 0                  | 1.3                |
|          | Natural resource use                      | 0.5                | 0.5                | 1.1                |
|          | Relevant FWM laws and regulations         | 1.1                | 0                  | 1.1                |
|          | Job opportunities                         | 1                  | 0                  | 1                  |
|          | Economic growth                           | 1                  | 0                  | 1                  |
|          | Bio-based industry availability           | 0                  | 0.9                | 0.9                |
|          | International directives                  | 0.8999999999999999 | 0                  | 0.8999999999999999 |
|          | Public awareness                          | 0.8                | 0                  | 0.8                |
|          | circular economy                          | 0.7                | 0                  | 0.7                |
|          | Information campaigns                     | 0.2                | 0.5                | 0.7                |

Figure 15:Results of the network analysis for FCM of academic members (part 2)

#### **4.2.3.2.2 FCM of retailing group**

The results showed that retailers' static scores fell within the middle range compared to other stakeholder groups. However, retailers ranked the second highest in terms of potential and adaptability to changes in the system to improve the KSA-FWM. This is attributed to their density, complexity, numbers of connections, and (C/N) scores, which were all within the mid-range compared to other stakeholders in this research.

FCM analysis of the retailing group (depicted in **Fig. 16** and **18** revealed that Information companies, Circular economy and R&D were identified as driver variables and exerted significant influence within the system. While Job opportunities, Relevant FWM regulations, Natural resource use, and Food security were categorized as receiver variables, and the remaining variables were classified as ordinary. Government policies and laws, followed by Government policies, Supply chain efficiency, Green management, Bio-industry availability, Climate change, Land degradation and Contamination emerged as the most important factors and components for KSA-FWM system based on the retailers' perspective due to their higher centrality values in Mental Modeler of their map (**Fig. 17** and **19**).

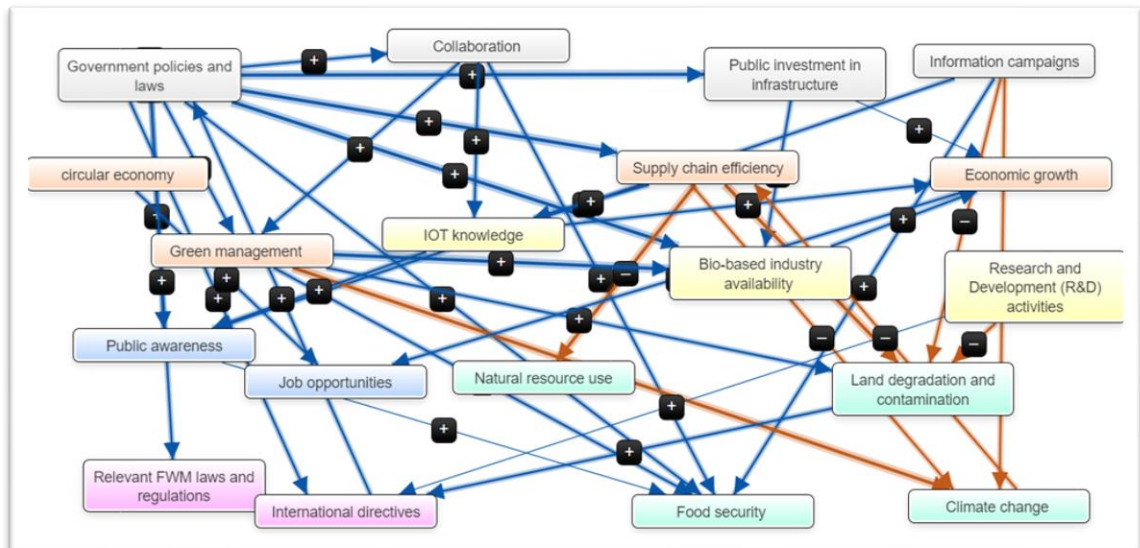


Figure 16: The FCM of retail sector group of FWM

| Component                                 | Indegree           | Outdegree          | Centrality         |
|-------------------------------------------|--------------------|--------------------|--------------------|
| Government policies and laws              | 0.2                | 4.02               | 4.22               |
| Collaboration                             | 0.41               | 0.8200000000000001 | 1.23               |
| Public investment in infrastructure       | 0.6                | 0.33               | 0.9299999999999999 |
| Information campaigns                     | 0                  | 1.24               | 1.24               |
| circular economy                          | 0                  | 0.46               | 0.46               |
| Supply chain efficiency                   | 0.93               | 1.76               | 2.69               |
| Green management                          | 0.6                | 1.62               | 2.22               |
| Economic growth                           | 0.85               | 0.3                | 1.15               |
| Public awareness                          | 0.95               | 0.14               | 1.0899999999999999 |
| Job opportunities                         | 0.76               | 0                  | 0.76               |
| IOT knowledge                             | 0.7                | 0.52               | 1.22               |
| Bio-based industry availability           | 1.26               | 0.47               | 1.73               |
| Research and Development (R&D) activities | 0                  | 0.39               | 0.39               |
| Relevant FWM laws and regulations         | 0.45               | 0                  | 0.45               |
| Land degradation and contamination        | 1.25               | 0.33               | 1.58               |
| International directives                  | 0.8300000000000001 | 0.2                | 1.03               |
| Natural resource use                      | 0.5                | 0                  | 0.5                |
| Climate change                            | 1.2                | 0.4                | 1.6                |
| Food security                             | 1.5100000000000002 | 0                  | 1.5100000000000002 |

Figure 17: Results of the network analysis for FCM of retail group

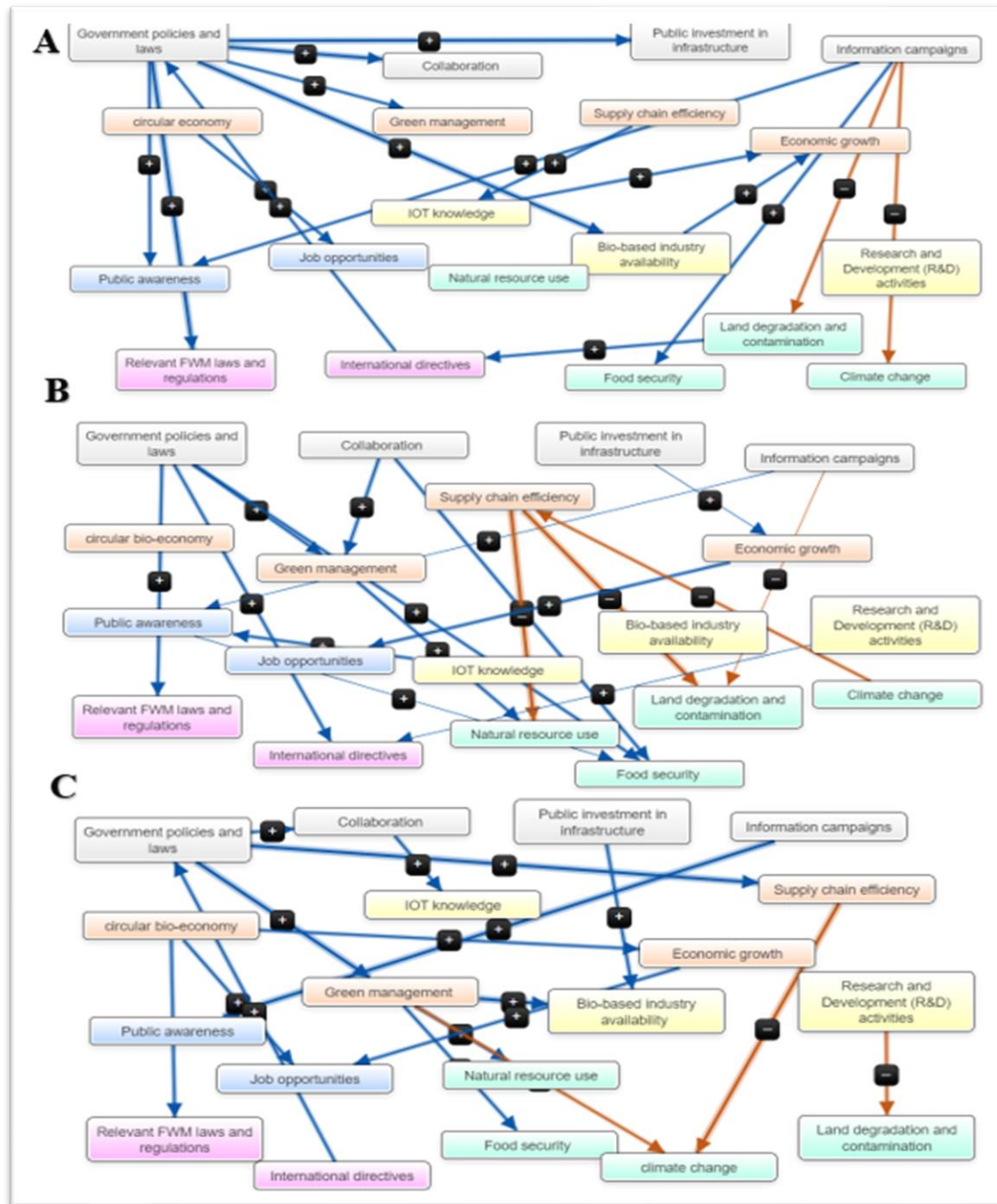


Figure 18 (a,b,c):Individual FCMs collected from 3 retail members

| A | Component                                 | Indegree | Outdegree          | Centrality         |
|---|-------------------------------------------|----------|--------------------|--------------------|
|   |                                           |          |                    |                    |
|   | Government policies and laws              | 0.2      | 3.11               | 3.31               |
|   | Information campaigns                     | 0        | 1.3                | 1.3                |
|   | Bio-based industry availability           | 0.5      | 0.47               | 0.97               |
|   | Economic growth                           | 0.78     | 0                  | 0.78               |
|   | IOT knowledge                             | 0.46     | 0.31               | 0.77               |
|   | Public awareness                          | 0.69     | 0                  | 0.69               |
|   | Land degradation and contamination        | 0.35     | 0.33               | 0.6799999999999999 |
|   | Relevant FWM laws and regulations         | 0.6      | 0                  | 0.6                |
|   | Public investment in infrastructure       | 0.6      | 0                  | 0.6                |
|   | International directives                  | 0.33     | 0.2                | 0.53               |
|   | Collaboration                             | 0.53     | 0                  | 0.53               |
|   | Green management                          | 0.48     | 0                  | 0.48               |
|   | Job opportunities                         | 0.47     | 0                  | 0.47               |
|   | circular economy                          | 0        | 0.47               | 0.47               |
|   | Supply chain efficiency                   | 0        | 0.46               | 0.46               |
|   | Climate change                            | 0.4      | 0                  | 0.4                |
|   | Food security                             | 0.26     | 0                  | 0.26               |
|   | Natural resource use                      | 0        | 0                  | 0                  |
|   | Research and Development (R&D) activities | 0        | 0                  | 0                  |
| B | Component                                 | Indegree | Outdegree          | Centrality         |
|   |                                           |          |                    |                    |
|   | Supply chain efficiency                   | 0.4      | 1                  | 1.4                |
|   | Government policies and laws              | 0        | 1.26               | 1.26               |
|   | Food security                             | 0.9      | 0                  | 0.9                |
|   | Natural resource use                      | 0.79     | 0                  | 0.79               |
|   | Green management                          | 0.43     | 0.29               | 0.72               |
|   | Land degradation and contamination        | 0.63     | 0                  | 0.63               |
|   | Collaboration                             | 0        | 0.5800000000000001 | 0.5800000000000001 |
|   | International directives                  | 0.5      | 0                  | 0.5                |
|   | Public awareness                          | 0.32     | 0.14               | 0.46               |
|   | Climate change                            | 0        | 0.4                | 0.4                |
|   | Economic growth                           | 0.07     | 0.27               | 0.34               |
|   | Relevant FWM laws and regulations         | 0.3      | 0                  | 0.3                |
|   | Job opportunities                         | 0.27     | 0                  | 0.27               |
|   | Information campaigns                     | 0        | 0.24               | 0.24               |
|   | IOT knowledge                             | 0        | 0.21               | 0.21               |
|   | Research and Development (R&D) activities | 0        | 0.15               | 0.15               |
|   | Public investment in infrastructure       | 0        | 0.07               | 0.07               |
|   | Bio-based industry availability           | 0        | 0                  | 0                  |
|   | circular bio-economy                      | 0        | 0                  | 0                  |

**C**

| Component ▼                               | Indegree ▼ | Outdegree ▼ | Centrality ☑ |
|-------------------------------------------|------------|-------------|--------------|
| Green management                          | 0.53       | 1.4         | 1.93         |
| Government policies and laws              | 0.43       | 1.35        | 1.78         |
| circular bio-economy                      | 0          | 1.1         | 1.1          |
| Supply chain efficiency                   | 0.53       | 0.5         | 1.03         |
| climate change                            | 0.8        | 0           | 0.8          |
| Job opportunities                         | 0.78       | 0           | 0.78         |
| Bio-based industry availability           | 0.76       | 0           | 0.76         |
| Economic growth                           | 0.42       | 0.33        | 0.75         |
| Public awareness                          | 0.63       | 0           | 0.63         |
| Information campaigns                     | 0          | 0.63        | 0.63         |
| Collaboration                             | 0.29       | 0.24        | 0.53         |
| International directives                  | 0          | 0.43        | 0.43         |
| Food security                             | 0.35       | 0           | 0.35         |
| Public investment in infrastructure       | 0          | 0.26        | 0.26         |
| Natural resource use                      | 0.25       | 0           | 0.25         |
| Land degradation and contamination        | 0.24       | 0           | 0.24         |
| Research and Development (R&D) activities | 0          | 0.24        | 0.24         |
| IOT knowledge                             | 0.24       | 0           | 0.24         |
| Relevant FWM laws and regulations         | 0.23       | 0           | 0.23         |

Figure 19(a, b, c): Results of the network analysis for FCM of retail members

#### 4.2.3.2.3 FCM of government official group

The Saudi Recycling Company (SRIC), a government entity, presents a complex map characterized by higher complexity scores compared to the retailing group. In contrast, number of connections, and other variables scores exhibit the lowest values compared to the retailing group. Within SRIC's map, the driving (transmitter) factors were Government policies and Economic growth, while Collaboration, Job opportunities, Public awareness, and Natural resource use were identified as receiving factors. Furthermore, both the recycling group and the retailing group exhibited the same value in density, which indicates slight room for adaptation or change in FWM compared to Academia stakeholders. However, despite this similarity, the score of (C/N) in recycling model had the lowest value which indicated the highest degree of connectedness among all other stakeholder groups (**Table 15**). Green management followed by Circular economy, Collaboration, Information campaigns, International directives, and Government policies are identified as the most significant factors and components for KSA-FWM system based on the retailers' perspective due to their higher centrality values within the Mental Modeler representation of their map (**Fig. 20** and **21**).

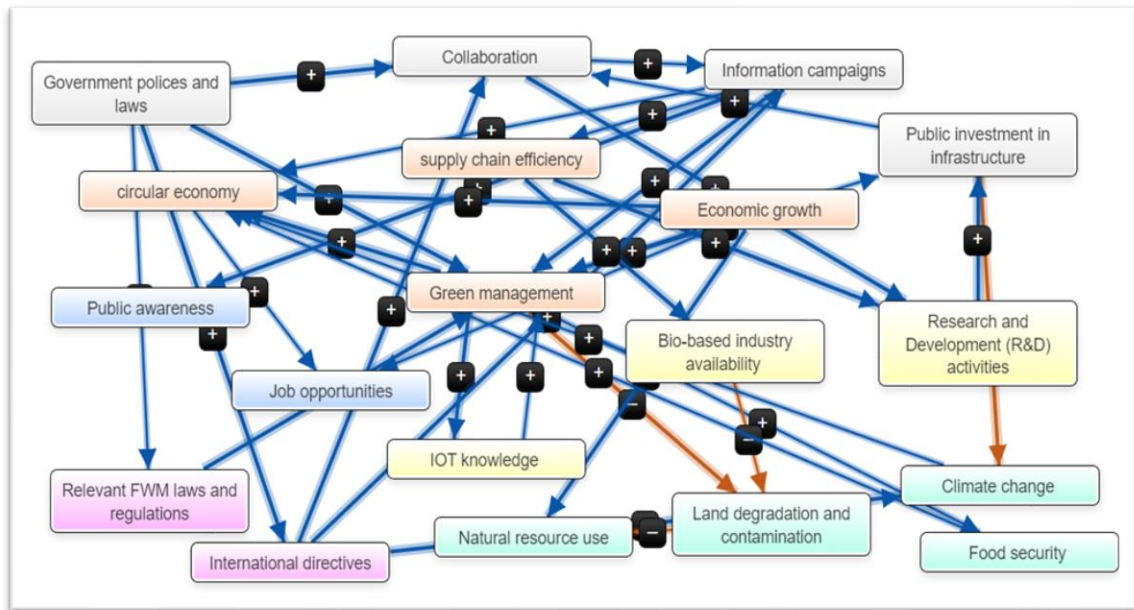


Figure 20: The FCM of official group of FWM

| Component                                 | Indegree           | Outdegree          | Centrality         |
|-------------------------------------------|--------------------|--------------------|--------------------|
| Green management                          | 2.4499999999999997 | 2.4699999999999998 | 4.92               |
| circular economy                          | 2.87               | 0.4                | 3.27               |
| Collaboration                             | 1.7599999999999998 | 0.93               | 2.69               |
| Information campaigns                     | 1.02               | 1.6500000000000001 | 2.67               |
| International directives                  | 0.56               | 1.9300000000000002 | 2.49               |
| Government polices and laws               | 0                  | 2.29               | 2.29               |
| Economic growth                           | 0                  | 2.2399999999999998 | 2.2399999999999998 |
| Research and Development (R&D) activities | 1.1                | 0.51               | 1.61               |
| Climate change                            | 1.1                | 0.48               | 1.58               |
| Public investment in infrastructure       | 0.71               | 0.85               | 1.56               |
| supply chain efficiency                   | 0.2                | 1.1099999999999999 | 1.3099999999999998 |
| Land degradation and contamination        | 0.8699999999999999 | 0.3                | 1.17               |
| Relevant FWM laws and regulations         | 0.43               | 0.5                | 0.9299999999999999 |
| Natural resource use                      | 0.9099999999999999 | 0                  | 0.9099999999999999 |
| IOT knowledge                             | 0.5                | 0.39               | 0.89               |
| Job opportunities                         | 0.89               | 0                  | 0.89               |
| Food security                             | 0.39               | 0.45               | 0.8400000000000001 |
| Bio-based industry availability           | 0.54               | 0.3                | 0.8400000000000001 |
| Public awareness                          | 0.5                | 0                  | 0.5                |

Figure 21: Results of the network analysis for FCM of official group

#### 4.2.3.2.4 Community Map (CFCM)

Social FCM represents a comprehensive whole system's map. It aggregated all stakeholder group's maps of the KSA-FWM to evaluate the roles of the stakeholder interactions (**Fig. 22**). The direction of the connecting arrow indicates the causal influence relationship between factors, while the thickness of the arrow signifies the strength of the relationship. The colors denoted their positive casual relationships (blue) and negative causal relationships (red) within the network. The causal relations between the variables are shown as arrows (J. Halbrendt et al., 2014).

The results of the social mapping exercise demonstrate that the variable great exhibits the highest number of ties (160) within the system, with an average degree of 8.4, and a density of 0.5. These metrics signify a substantial potential for adaptation and room for changes within the system to develop management of food waste in Saudi Arabia (KSA-FWM). Both driving and receiving factors register values of zero, while the ordinary factor attains the maximum value in the system. Notably, the social map illustrates a lack of forcing factors influencing others or being influenced by them. Consequently, the map suggests a moderate level of complexity and delineates the roles and interactions of factors throughout the system. According to the social map results, the important factors affecting KSA-FWM are Green management, followed by Government policies, R&D activities, Supply chain efficiency, Economic growth, and Collaboration (**Fig. 23**).

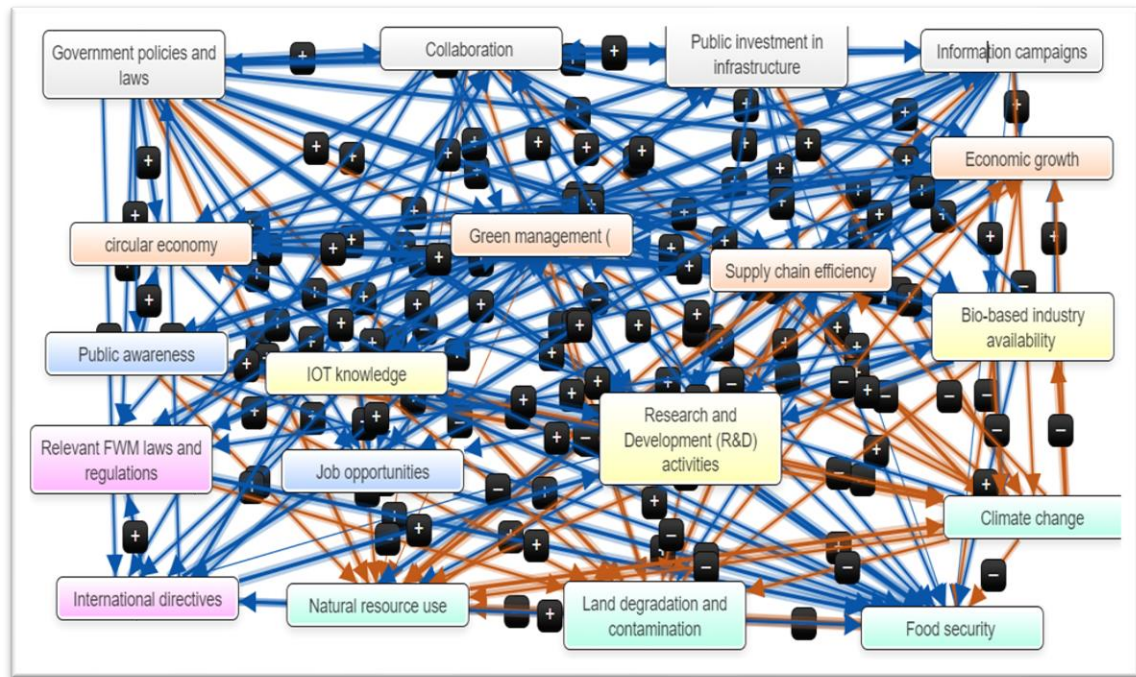


Figure 22: The Community Map (CFCM)

| Component                                 | Indegree           | Outdegree          | Centrality         |
|-------------------------------------------|--------------------|--------------------|--------------------|
| Green management                          | 4.87               | 6.94               | 11.81              |
| Government policies and laws              | 0.96               | 9.22               | 10.18              |
| Research and Development (R&D) activities | 5.18               | 4.510000000000001  | 9.690000000000001  |
| Supply chain efficiency                   | 4.44               | 5                  | 9.440000000000001  |
| Economic growth                           | 5.1499999999999995 | 4.04               | 9.19               |
| Collaboration                             | 2.71               | 6.160000000000001  | 8.870000000000001  |
| Food security                             | 7.530000000000001  | 0.45               | 7.980000000000001  |
| Climate change                            | 4.83               | 3.05               | 7.88               |
| IOT knowledge                             | 3.3400000000000003 | 4.3999999999999995 | 7.74               |
| Bio-based industry availability           | 3.5000000000000004 | 3.7600000000000002 | 7.260000000000001  |
| circular economy                          | 5.459999999999999  | 1.48               | 6.9399999999999995 |
| Public investment in infrastructure       | 1.7999999999999998 | 4.2700000000000005 | 6.07               |
| Information campaigns                     | 1.63               | 4.36               | 5.99               |
| Natural resource use                      | 4.289999999999999  | 1.46               | 5.749999999999999  |
| Land degradation and contamination        | 3.9399999999999995 | 1.58               | 5.52               |
| International directives                  | 2.01               | 3.45               | 5.46               |
| Relevant FWM laws and regulations         | 2.66               | 2.08               | 4.74               |
| Public awareness                          | 1.98               | 2.74               | 4.720000000000001  |
| Job opportunities                         | 3.1700000000000004 | 0.5                | 3.6700000000000004 |

Figure 23: Results of the network analysis for CFCM

#### 4.2.3.3. FCM Dynamic analysis (scenario simulation)

The scenario analysis offers evidence of the pivotal role played by government policies and green management in guiding and influencing other variables within the system towards desirable and sustainable management practices. FCMapper platform tool was utilized for answering the stimulation question “How can the policy actions and green management practices such as composting, recycling, biorefinery, etc. support in designing and development of the KSA-FWM? For this analysis, steady states (s.s) of variables were determined and extracted which were derived from stakeholders’ insights and community FCM. **Table 16** and **17** presented the calculation of steady states (s.s), scenarios (s.s), and the disparities discerned between scenarios. The term (s.s) denotes the baseline of the model outcomes in the absence of any external interventions. Scenarios (s.s) represent the values of variables or factors subsequent to the implementation of specific concepts and scenarios. The (s.s) values were obtained through 20 iterations until the factor values attained a steady state, indicating that the vectors remained consistent across iterations. Subsequently, two distinct scenarios were implemented, as depicted in **Figures 24** and **25**, illustrating alterations in the model aimed at modifying the current unsustainable KSA-FWM.

Table (16): Steady state (S.S) of model variables

| ID | Variables                           | Steady state s.s. |
|----|-------------------------------------|-------------------|
| P1 | Government policies and laws        | 0.85141           |
| P2 | Collaboration                       | 0.970860          |
| P3 | Public investment in infrastructure | 0.932858          |
| P4 | Information campaigns               | 0.9191097         |
| C1 | Circular economy                    | 0.9969184         |
| C2 | Green management                    | 0.996474          |
| C3 | Supply chain efficiency             | 0.9923045         |
| C4 | Economic growth                     | 0.992569          |
| S1 | Public awareness                    | 0.943259          |
| S2 | Job opportunities                   | 0.982958          |
| T1 | IOT knowledge                       | 0.984585          |
| T2 | Bio-based industry availabilities   | 0.979199          |
| T3 | R&D activities                      | 0.9973193         |
| L1 | Relevant FWM laws and regulations   | 0.9705172         |
| L2 | International directives            | 0.926589          |
| E1 | Natural resource use                | 0.1010589         |
| E2 | Land degradation and contamination  | 0.035913          |
| E3 | Climate change                      | 0.029373          |
| E4 | Food security                       | 0.996891          |

Table (17): S.S and differences of model variables for both scenarios

| ID | Variables                           | Scenario s.s.<br>(2) | Scenario s.s. (3) | Scenario s.s.(2)<br>– s.s. | Scenario s.s.(3)<br>– s.s. |
|----|-------------------------------------|----------------------|-------------------|----------------------------|----------------------------|
| P1 | Government policies and laws        | 1.00                 | 0.851418087       | 0.14859045                 | 0.00000854                 |
| P2 | Collaboration                       | 0.973277412          | 0.970884723       | 0.00241696                 | 0.00002427                 |
| P3 | Public investment in infrastructure | 0.937605351          | 0.932908189       | 0.00474739                 | 0.00005023                 |
| P4 | Information campaigns               | 0.924159473          | 0.919172567       | 0.00504975                 | 0.00006284                 |
| C1 | Circular economy                    | 0.997188019          | 0.996927432       | 0.00026961                 | 0.00000902                 |
| C2 | Green management                    | 0.996755308          | 1.00              | 0.00028082                 | 0.00352552                 |
| C3 | Supply chain efficiency             | 0.99296411           | 0.99231795        | 0.00065959                 | 0.00001343                 |
| C4 | Economic growth                     | 0.993467             | 0.992588599       | 0.00089749                 | 0.00001918                 |
| S1 | Public awareness                    | 0.946709             | 0.94332165        | 0.00345015                 | 0.00006270                 |
| S2 | Job opportunities                   | 0.984080             | 0.98299444        | 0.00112272                 | 0.00003689                 |
| T1 | IOT knowledge                       | 0.985860             | 0.984613          | 0.00127464                 | 0.00002831                 |
| T2 | Bio-based industry availabilities   | 0.980760             | 0.979236          | 0.00156134                 | 0.00003785                 |
| T3 | R&D activities                      | 0.997610             | 0.997325          | 0.00029083                 | 0.00000519                 |
| L1 | Relevant FWM laws and regulations   | 0.972595             | 0.970582          | 0.00207826                 | 0.00006503                 |
| L2 | International directives            | 0.931339             | 0.926693          | 0.00475020                 | 0.00010383                 |
| E1 | Natural resource use                | 0.093605             | 0.101036          | -0.00745430                | -0.00002311                |
| E2 | Land degradation and contamination  | 0.033035             | 0.035884          | -0.00287742                | -0.00002848                |
| E3 | Climate change                      | 0.028050             | 0.029339          | -0.00132351                | -0.00003430                |
| E4 | Food security                       | 0.997192             | 0.996897          | 0.00030042                 | 0.00000531                 |

#### **4.2.3.3.1 Government policies scenario**

In this scenario, we simulated only one political factor “Government policies and laws” to forecast the impact on other model variables via forcing a maximum value 1 of simulation to the weight of aforementioned factor. Consequently, the scenario’s outcomes were manifested as differentials in (s.s) values, as detailed in **Figure 24**. As expected, it showed high positive responses across various system variables. It also presented that Government policies and laws factor is emerged as pivotal driver, especially fostering cooperation, public investment in infrastructure, and information campaigns. It has a significant role in supporting economic and social sectors. Nonetheless, it also resulted in the adverse influences on the environmental factors such as natural resource utilization, land degradation and contamination, and climate change.

#### **4.2.3.3.2 Green management scenario**

In this scenario, we simulated only one economic factor “Green management” assigning a maximum simulated weight of 1 to its influence. The results of this simulation, depicted in **Figure 25**, reveal a notable positive trend across a majority of system variables. Specifically, enhancements are observed in Relevant FWM laws and regulations, International directives, Public investment in infrastructure, Information campaigns, and Public awareness. The green management simulation outcomes were evident of potential alternatives that could tackle the environmental issues such as Natural resource use, Land degradation and contamination, and Climate change. Furthermore, this is an important factor in transforming traditional KSA-FWM into a more environment friendly alternative within the food business sectors.

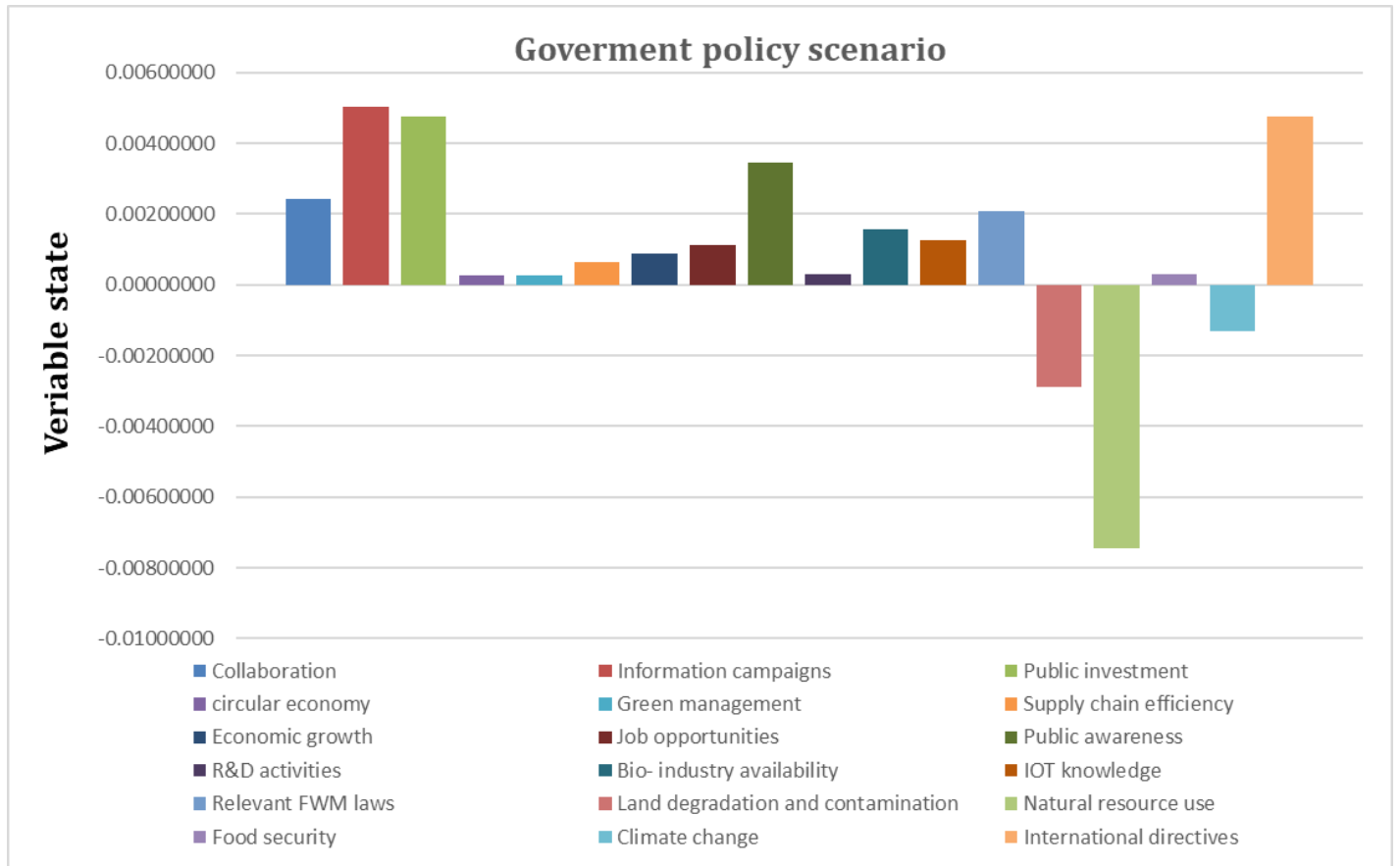


Figure 24: Relative strength of factors under government policy scenario values that relative change from the steady state and the results of increasing maximum only one factor the government policy and not across factors.

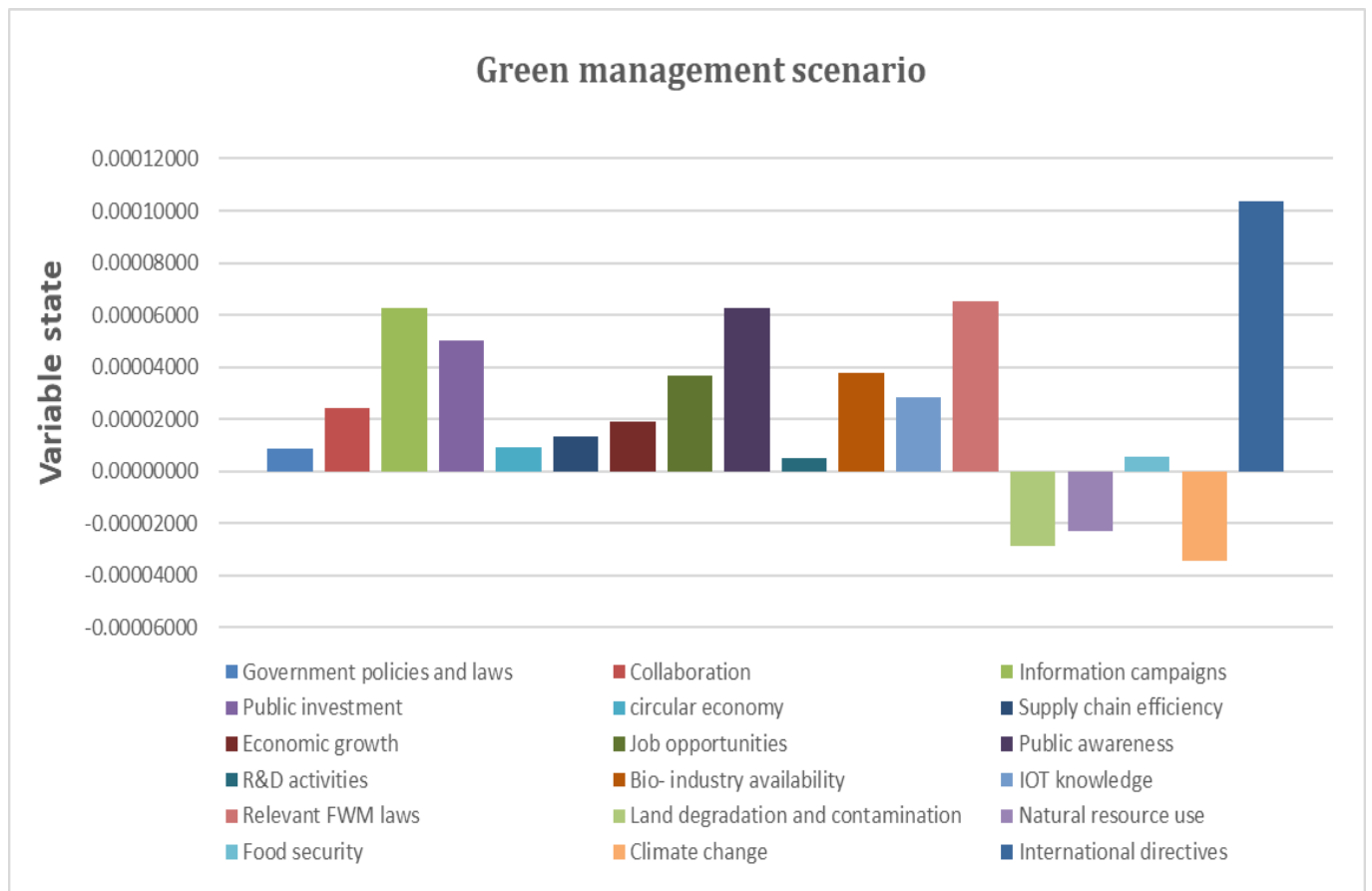


Figure 25: Relative strength of factors under green management scenario values that relative change from the steady state and the results of increasing maximum only one factor the green management and not across factors.

## **4.3 Discussion**

### **4.3.1. Public Awareness, knowledge, and habit towards Sustainable FWM**

The Majority of respondents had limited awareness of FW terminologies, a finding consistent with previous studies conducted in the U.S. (Di Talia et al., 2019; Neff, 2015), and in other countries (Heng, 2022). Food sharing and redistribution emerged as the best practices for reducing FW as expressed by the respondents of the study. Conversely, existing literature suggests that the most favoured approach involves source prevention to curtail FW generation, followed by the reuse of food for human consumption, with recycling options such as composting, and animal feeding ranked as less desirable alternatives. Prioritizing of FWM options according to the waste hierarchy holds significant promise for better decision-making and offers environmental, social, and economic advantages (Garcia-Garcia, 2017; Garcia-Garcia et al., 2015).

The majority of respondents of the survey were young women, and there is evidence that younger women are more responsible and aware of FW sustainability and its associated impacts (Alsawah et al., 2022). However, contrasting findings exist, with some studies indicating that female shoppers, in general, contribute to higher rates of food waste (Heng, 2022). The study's findings underscored the significance of key factors influencing FW awareness, notably age, gender, household size, and employment status (particularly among students), a trend consistent with prior research outcomes (Debrah, Vidal, & Dinis, 2021; Licy, 2013; Mumtaz, 2022). Moreover, in this survey, income level did not influence FWM practices. FWM knowledge does not differ much between low-income and high-income consumers (Thi, 2015).

Analysis reveals that a high percentage of uncertain responses, indicated by “not sure” option were due to a lack of public knowledge and awareness of FWM, coupled with lack of practical environmental legislation and correct practices in this regard. These findings are consistent with prior investigations (Baig, Al-Zahrani, et al., 2018; Di Talia et al., 2019; Licy, 2013). Consequently, providing clear environmental guidelines and social instructions on how to manage and classify FW at source through the presence of social media networks and technologies were indicated as positive responses in this study. For example, use of the Internet of Things (IOT) through the deployment of smart bins are used to enhance waste collection activities as well as monitoring the volume and weight of waste. These gadgets will alter positively the community attitudes that would lead to FW prevention and sustainability. Notably, these findings are consistent with earlier research endeavors (Abdullah et al., 2022; GOV.UK., 2017).

Several laws deemed effective and reinforced for implementation may not garner strong support from respondents, as evidenced in this study. These outcomes parallel findings in related research (Alsawah et al., 2022). Encouraging awareness among colleges and schools would help young people understand the value of food and ways to reduce food waste, especially in early childhood, as suggested by numerous survey responses. These insights align with prior investigations (GOV.UK., 2017; Licy, 2013; Mumtaz, 2022).

Respondents identified FWM as an integrated responsibility between the community and relevant agencies, contributing to national sustainability, which support SDG 11.6: Reduce the Environmental Impact of Cities and SDG 12.3: Addressing Food Loss and Waste (UN, 2022). Planning what to purchase and preparing a shopping list encourage food waste reduction at source. The finding supports former studies that have revealed that

checking food levels at home before shopping helps to avoid buying large quantities of unnecessary food, preventing food waste (Quested, 2013). Furthermore, this research determined that promotional offers by retailers can influence individual's shopping attitudes and elevate food waste levels. Similar results have been found across different countries (Heng, 2022; Radzymińska, 2016).

The study's findings are encouraging in terms of the respondents' acceptance of acquiring environmental knowledge, following instructions, and adhering to guidelines for managing their FW. Additionally, some positive attitudes were noted in the study, i.e., recycling actions (**Table 8**), making a shopping list, and their sense of responsibility for reducing FW. On the other hand, there is still a need to promote and emphasize FWM within environmental learning along with practical applications for addressing the prevailing ambiguity in people's perceptions. These results are consistent with research argument that environmental learning is lacking in most developing countries attributing it to the limited implementation of practical strategies to tackle contemporary environmental challenges and achieve sustainability goals (Debrah et al., 2021; Licy, 2013). The study showed that respondents managed FW according to their preferred methods (animal husbandry and food redistribution), rather than relying on environmental knowledge or principles. Notably, food reduction at the source emerges as the participants' least favored approach for discarding FW, despite its prioritized status within waste management hierarchies (Cristóbal et al., 2018). The findings underscore the dynamic nature of individuals' attitudes towards environmental issues, shaped by their perceived connection and interdependence with nature. These evolving attitudes hold significant implications for achieving sustainability goals nationwide (Debrah et al., 2021). An integrated approach including environmental education,

governmental policies, and technological advancements, as depicted in **Figure 26** is essential for elevating the awareness of FWM within the community. Within the educational context, efforts must be coordinated across schools, universities, and research centers. Environmental education initiatives should implement waste segregation at all levels of schools and institutions to create new environmental norms to bridge the knowledge gaps between generations in waste management. Thus, educated young consumers can engage in sustainable FWM, which will have a large impact on society and the potential to further motivate people to contribute to reducing food waste.

Furthermore, conducting frequent studies and research to gauge society's awareness, in particular areas or regions, aids to propagate positive habits. Researchers should organize workshops and brainstorming sessions for providing information on FWM, demonstrating the benefits of waste sorting procedures, and identifying appropriate waste disposal destinations. Motivating private sectors (retailers, restaurants, and recycling companies) for designing public awareness campaigns for informing the public about the availability of alternatives in their country to engage and reduce their FW should be encouraged. For example, households could be encouraged to recycle their FW by providing and distributing free recycling bins and incentives for collecting waste. Furthermore, they should adopt the sustainable guidelines, skills, and technology from countries which are advanced in this field (Debrah et al., 2021; Falcone & De Rosa, 2020; Mganga, 2021). The government should formulate targeted laws, policies and clear directives and strategies to prevent FW and promote sustainable management to achieve SDG goals, especially SDG 11 and 12). Similarly, government officials and all relevant stakeholders should have direct regulations, economic and social tools, and responsibilities to avoid overlaps among

them (Abdullah et al., 2022; Jalloun, 2022; Liu, 2022; S. Wang, Wang, J., Zhao, S., & Yang, S., 2019).

Technology serves as a valuable instrument in advancing strategic processes and plans aimed at evaluating the performance of waste management systems to meet environmental standards. Technology can facilitate mobilization and increase awareness of FWM. In particular, social media platforms such as Twitter, Instagram, and YouTube can be leveraged to raise awareness of the consequences of FW and encourage food waste reduction activities such as implementation of 3Rs techniques. It will also improve consumer's environmental understanding and knowledge about managing food waste to reduce economic costs, environmental hazards, and social issues. FWM and prevention should be taught to the younger generation through social media to keep them informed about the FW ramifications. Likewise, retailers and restaurants should develop advertising messages, environmental campaigns, and programs via social media for motivating consumers to reduce FW. Concurrently, elucidating the function and purpose of IoT technology, which we intend to employ, can aid in augmenting awareness regarding the FW issue. For instance, recent advancements such as Smart Garbage Bins (SGBs) offer viable solutions to mitigate the volume of food waste and operational costs associated with waste collection systems, while also encouraging individuals to adopt waste segregation practices aimed at identifying appropriate waste recycling and treatment methods (Abdullah et al., 2022; Hong, 2014; Mumtaz, 2022).

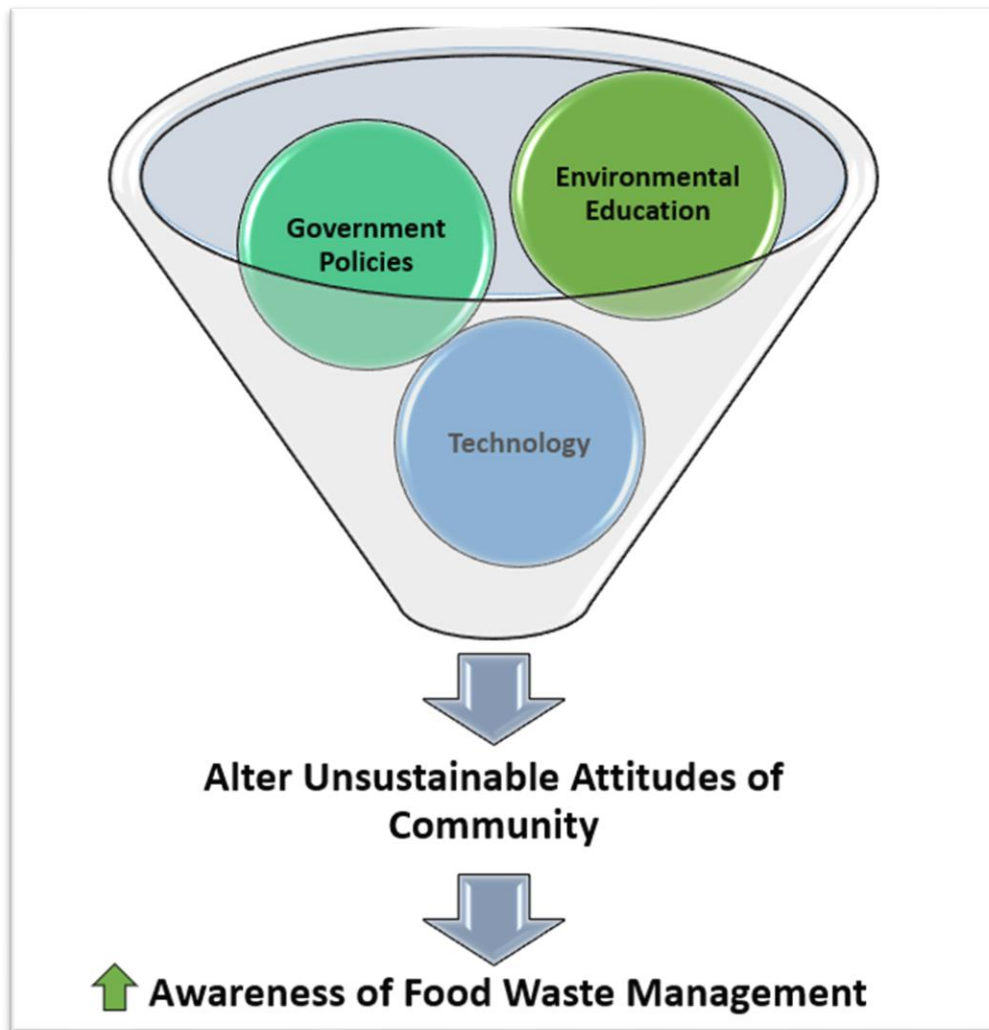


Figure 26: An integrated approach for increasing awareness of FWM

#### 4.3.2 FWMDT and the suggested sustainable FWM options

Although categorization of FW is an arduous process, it provides good support for decision-making aimed at selecting best management alternatives for FW with consideration of countries' regulations and environmental, social and economic influences. After identifying and categorizing each of the seven selected types of FW (Fruit and vegetable, Canned food, Egg and dairy products, Meat, Poultry and Fish, Cereals, Bread, and Ready meals) according to the guiding principles of the nine indicators described in depth

in **Chapter 3 (Section 3.4.2.1)**, the subsequent phase involves to select, identify, and analyze suitable FWM options. The proposed FWM alternatives involve five management options, starting with redistribution for human consumption, animal feeding, anaerobic digestion, composting and thermal treatment recovery. These management alternatives are underscored by the food waste management decision tree (FWMDT) which is deemed more practicable compared to the waste management hierarchy (WMH)-reduce, reuse, recycle, recover and disposal- for all the FW types. In addition, WMH classifies food waste as a whole and does not analyze and evaluate each type of FW separately. Since food is a heterogeneous mixture of different substances and there are many factors that affect food waste in the food supply chain, FWMDT must be applied for effective management decision-making. Furthermore, in the FWH, the prevention of FW is prioritized management option, and it is always at the top of the hierarchy since it is applicable to any type of edible FW (Sanchez Lopez, 2020). In contrast, the prevention of food waste is not involved in the FWMDT because it is always in the scope and high prioritization of FWM. The extraction and industrial use of compounds of interest are included in FWH, as a large number of value-added products can be extracted from FW and offer numerous possibilities for industrial applications. However, the FWMDT excludes them and replaces with AD following the nine indicators.

According to the FWMDT and its nine indicators, redistribution of surplus food for human consumption to people in need, charities, and food banks is a post-prevention priority and best management option. For the RD management option to be applied, the food must be edible, processed, and comply with the General Food Law (Union European, 2002, 2023), and the Saudi Food Hygiene Requirements Package (SFDA, 2020).

The animal feeding (AF) management option presents environmental and economic advantages due to reduce land use change for farming the crops utilized in AF and minimizing disposal costs through free or donated feed. Additionally, AF reduces the consumption of water, energy, and chemical fertilizers during food production (IGD, 2013). However, it is crucial to adhere to specific conditions outlined by FWMDT when employing AF. Notably, FW containing animal presence products (such as meat, animal products, and animal by-products) and catering food waste are excluded from this management option (Michael, 2017). The animal feeding (AF) option is deemed suitable for plant-based food waste and single products that are in an unpackaged state, and which may be in an inedible condition for humans but are consumable by animals, as shown in **Table 10** and **11** for the categories of Bread, Cereals and Grains, and Fruit and Vegetables. On the other hand, mixed FW with animal products can be used for animal feeding if they are not the main ingredient, and must be processed directly from the manufacturing stage under specific treatments (Murugesan, 2021).

Anaerobic digestion (AD) and composting are optimal management alternatives for most unpacked FW, particularly the mixed food waste containing meat or animal products. If the FW is packaged and cannot be separated from its packaging, the packaging should be biodegradable, such as made up of wood, paper, or cardboard. Furthermore, in order to apply composting as an option for managing FW including meat or animal products, in vessel composting method must be used to avoid vermin invasion (Garcia-Garcia et al., 2015; WRAP, 2012), bacteria, and viruses that could contaminate groundwater (EPA, 2004). For most types of FW that includes packaged food and contain meat or animal products, thermal treatment of waste into energy is the only sustainable alternative.

Waste-to-energy treatment involves incineration, pyrolysis, and gasification. In general, this treatment is a simple and rapid process and provides power from organic waste and minimizes its volumes. However, thermal treatment with energy recovery, as outlined by the FWMDT, is considered the least preferable alternative for FWM. This is primarily due to the pollutant emissions associated with the incineration process and its relatively low efficiency (Garcia-Garcia, 2017; Saha, 2023). In recent years, with the advancement of technology, heat treatment plants using the latest nanotechnology can reduce the emission of atmospheric pollutants and meet strict emission standards (Net, 2023; Saha, 2023).

Further possibilities for alternative utilization of food waste (FW) encompass foodstuff production, industrial applications, and land spreading, offering more sustainable management options to derive significant value and benefits from FW, particularly in the context of bread, cereal, and dairy products. Land spreading is an affordable and simple FWM option for farmers by spreading the FW of the inedible parts of the plant present onto their land (Shore, 2016). However, composting is more beneficial than land spreading, so composting is the fourth best management practice in FWMDT.

Organic waste contains valuable compounds that can be extracted and constituted into new foods or food additives. For example, fermenting yeast can be isolated from cereals and dairy products e.g., yogurt and cheese (Fleet & Mian, 1987; Osimani, 2022), fat and proteins from meat (Xie, 2022), and flour, bread and muffins, starch, and maltose sugar from spent grain and cereal (Jin, 2022).

Extraction of antimicrobial chemicals such as flavonoids, phenolic acids, and industrial fertilizers (Gupta, 2023) can also be achieved. Some FWs

(e.g. dairy products) can serve as suitable culture media for probiotic bacteria for the synthesis of substances such as bioethanol, polymers and lactic acid (Shah, 2000). In addition, spent grain can be used as pollutant remover in wastewater treatment (Jin, 2022).

### **4.3.3 Applicability of the FWMDT**

The applicability of FWMDT was validated through its efficiency to categorize and classify the selected types of the FW (seven groups) at the retailing sector of this research while providing the most appropriate FWM options, as deliberated in the previous section. FWMDT is a useful framework to monitor and evaluate the FW management and sustainability processes of food companies in the region.

It is a fundamental way to classify the type of FW at any stage of food supply chain, however, its applicability may encounter limitations. For example, as mentioned previously, the FWMDT framework works effectively on the designated types of FW, but there are other types of FW (beverages not included in the study) at the retailing sector which may require customized classification and management solutions to identify all different cases and types of FW. The FWMDT framework has been positively used at the upstream segment of the food supply chain (food manufacturing) (Garcia-Garcia et al., 2015; Garcia-Garcia et al., 2017).

On the other hand, FWMDT requires some improvements in order to further increase the efficiency of FWM in a sustainable manner, especially for

implementation in the case of KSA. It must adapt the Saudi's regulations and health and safety requirements besides following international laws, and environmental guidelines.

Moreover, assessing FW in mixed products such as ready meals and animal feeding presents difficulties. For example, FW from ready meals or those customized for animal feeding analyzes the entire product without distinguishing between plant and animal-based components. To address this issue, it is essential to isolate and study each type of FW separately, if feasible, to facilitate the application of more sustainable management strategies tailored to each food type.

Another complexity is the difficulty of applying some of FWMDT's management solutions in Saudi Arabia, such as AD and thermal waste-to-energy treatment, primarily owing to unavailability of advanced technologies and bio-factories to carry out the required processes. Although Saudi Arabia might be slightly late for development compared to developed countries like US or UK, but now it has the latest technology with extreme efficiency helping to reach sustainability in SDGs (12.3 and 11).

Moreover, assessing FW in mixed products such as ready meals and animal feeding presents difficulties. For example, FW from ready meals or those customized for animal feeding analyzes the entire product without distinguishing between plant and animal-based components. To address this issue, it is essential to isolate and study each type of FW separately, if feasible, to facilitate the application of more sustainable management strategies tailored to each food type.

Although the packaged FW product is a great way to maintain the eatable FW free from contamination for RD option, the packaging could be issued

particularly in uneatable FW to adopt the most beneficial AD or affordable (composting) alternatives. Furthermore, the feasibility of unpacking from packaging and sending to AD or composting would require complex technology, which is currently not accessible in the country.

#### **4.3.4 Static and dynamic analysis of the model**

This study endeavors to compare the cognitive frameworks of various food stakeholder groups and broader societal perceptions. It delves into the interplay, perspectives, and knowledge of Saudi food stakeholders concerning FWM within the KSA, employing fuzzy cognitive mapping techniques to articulate their ideologies and visions. FCM serves as a tool to elucidate stakeholder priorities, mitigate conflicts, and enhance the efficacy of local regulatory frameworks and initiatives.

Through static analysis, the study revealed several shared elements across stakeholders' cognitive maps. Notably, participants commonly emphasized the significance of governmental intervention and policy formulation, collaborative endeavors among local food entities encompassing both public and private sectors, synchronization between food demand and supply chains, advocacy for environmentally sustainable practices encompassing green management, fostering public awareness, and instilling environmentally conscious attitudes within food production processes (Aditya & Kurniawati, 2023; Emir & Ekici, 2023; Falcone & De Rosa, 2020; Falcone, Lopolito, & Sica, 2018; Morone, 2021; Munir, 2022). The findings of this study have been corroborated by different studies in terms of the political, economic, and social factors as these are the key factors that can have a beneficial and positive impact on KSA-FWM.

Furthermore, study reveals that the level of the stakeholders' sustainable management knowledge is inadequate enough to guide and manage food

waste in a sustainable way. This deficiency is underscored by the undefined complexity score (0) observed in the social FCM outcomes, indicating a notable absence of the receiver factor within the model. In other words, there are not implications derived from network (Eden, Ackermann, & Cropper, 1992). In fact, this could be a sign of a complexity of the system that presents significant interlinkages and influences between model factors and variables (Henly-Shepard, 2015).

Although there are some similarities, it also shows some differences among FCMs as shown in static results. For example, the academia FCM is more diverse from others due to high complexity. The complexity score of academia group FCM is not definite (infinity) due to the ratio of the total number of the receiver (1) to the total number of driver (0) variables within the group map. This result underscores that the greater number of outcomes correlates with the high complexity of the map and low forcing factors on the system (Eden et al., 1992). Whist the retailer group exhibited moderation among other participants' role interactions and perspectives due to their average scores of all static results. Official government group (recycling group) has the opportunity to change the system based on their density scores, which are similar to retail groups but with high complexity scores and less connections between system variables. This may be because recycling members are generally more concerned with the economic value of FW than with social and environmental factors. Previous research suggests that government agencies and scientists often possess slightly more knowledge and expertise in the field compared to other stakeholders, underpinning their capacity for transformative action (C. Gray, Clark & Jordan, 2012; J. Halbrecht, Gray, S. A., Crow, S., Radovich, T., Kimura, A. H., & Tamang, B. B., 2014; Özesmi & Özesmi, 2004; Saint Ville, 2017)

Despite these divergent values within FCMs, all stakeholders can adapt to a new sustainable management. However, it should be under governmental regulation and oversight to ensure that environmental procedures are completely enlightened. This is evident in the high-density, number of connections, and the score of complexity of the community map within this research, as corroborated by previous studies (MacDonald, 1983; Sandell, 1996).

The FCM determines the in-degree, out-degree and, centrality of each model (refer to **Fig. 12, 14, 15, 17, 19, 21, and 23**), which illustrates the most important factors in each model as well as the variables that are assumed to have the most significant impact on the dynamics of KSA-FWM. Additionally, changes in structural metrics of these models signify stakeholders' introspection and deliberation on their interactions, beliefs, and mental models (N. A. Jones, Ross, H., Lynam, T., Perez, P., & Leitch, A., 2011).

The dynamic analysis further explores the roles of the stakeholder's interactions within KSA-FWM in addressing the research question "what are the changes in current food management practices that might lead to the sustainability and reduction in food waste in Saudi Arabia?". Therefore, different simulations are employed to predict potential improvements and design appropriate strategies and practices for KSA-FWM. The dynamic analysis demonstrates possible policy strategies would be adopted through government policies and laws and/or green management initiatives. These factors may have different effects on different variables that characterize FWM approaches. In addition, due to the strengthening/weakening effects produced by fuzzy analysis, the combined effect of two different variables presents a certain complexity (P. Morone, Falcone, P. M., & Lopolito, A., 2019). The model scenarios indicated the importance of political factor for

enforcing policies and regulations, thereby exerting control over FWM processes and actions. The model scenarios indicate the following potentially optimal strategies and policy recommendations for KSA-FWM:

- i) Enforcing policies and regulations would control FWM processes and actions among stakeholders' and prepares stakeholders for future unforeseen scenarios. According to the (Al-Khateeb et al., 2021), amount of FW will be reduced by half if there is FW regulations. For example, the wasted rice would decrease from 557 thousand tons to 279 thousand tons per year, and grains and breads from 917 thousand tons every year to 459 thousand tons with the enactment of FW regulations.
- ii) Promoting Information campaigns and raising public awareness would introduce new alternatives of management and reduction of FW by means of enhancing the stakeholders' responsibility and commitments (Johansson, 2018). From the perspective of supply chain efficiency, government laws could mandate food producers to adhere to optimal food standards, thereby integrating all stakeholders in managing the complexity of food supply and demand. The role of information campaigns serves as a form of peer monitoring aimed at reducing the illegal waste disposal through two ways. Firstly, government laws can penalize those who waste the food through fines. Secondly, individuals can easily persuade others not to waste food, increasing positive attitudes toward food consumption and management (Z. Zhang, & Zhao, L., 2019). Public awareness plays a role in minimizing unsustainable management and consumption patterns and acts as a means of enhancing environmental education, promoting innovative consumption practices, and fostering a culture of sharing food resources (Hanssen, 2015). Although

the sharing food and food bank carry socio-economic value, people still resist such management options (Michelini, 2018). To effectively implement circulation and dissemination of knowledge and innovations through social media, strategies must be tailored to reach various targeted groups, considering the diverse categories of stakeholders. For example, retail sector is interested in the economic and technological aspects related to zero waste types of food chain supply. In contrast, household members are more interested in understanding how new innovative alternatives impact their economic well-being (P. Morone, Falcone, P. M., & Lopolito, A., 2019).

- iii) Promoting circular economy involves embracing technological innovations such as IOT knowledge, green management initiatives and the availability of biorefineries. These green alternatives encourage sustainable practices in agro business, including composting, recycling, anaerobic digestion, and producing value-added products. Meanwhile it incentivizes fostering circular economy, minimizing environmental impacts, and achieving Net Zero by 2060. Composting is often more favorable for reducing global warming potential due to reduced GHG emissions compared to landfilling (Khandelwal, 2019). Environmental governance and investment and funds for environmental projects should receive more attention, alongside incentivizing industry actions toward Green management (Ananno et al., 2020). Biorefineries are an innovative way to add economic value to FW. However, the concept of biorefineries is not widely adoptive in the region due to the absence of such plants, even as FW becomes a crucial raw material for biorefineries. From an economic perspective, reducing FW may lead to

the closure of biorefineries. In this case, we must make it clear that biorefineries only add value to unavoidable FW (Morone, 2021).

- iv) Fostering research and innovation in collaboration with universities, research institutions and stakeholders is essential to assess current and potential FWM to provide better management solutions. In addition to R&D, the activity requires complex and high-tech equipment and cost of which could be shared between different participants and stakeholders. Thus, the collaboration will facilitate the transaction process (Veugelers, 2005).

Overall, strategies and scenario recommendations of this research have been designed to shift current unsustainable food waste management patterns to more sustainable patterns. It is crucial to balance and consider the potential ramifications of the proposed interventions to ensure effective implementation and mitigate adverse effects.

#### **4.4 Chapter Summary**

This chapter has provided the results of the research methodologies employed in this research and their subsequent in-depth discussion. Initially, the chapter investigated the levels of knowledge, awareness, and attitudes regarding sustainable FWM. The findings underscore the significant need for more efforts to enhance practical awareness and environmental education across various sectors, including educational, governmental, and private sectors. Secondly, it presented the results of using the FWMDT framework in three case studies of the retail sector in the city of Al-Khobar. The applicability of the framework was demonstrated through the implementation of various management options, highlighting its effectiveness in practical scenarios. Finally, the chapter described and identified the stakeholders' role and perspective interactions regarding FWM through designing

models and FCMs and setting different scenarios (Government policies and green management) for sustainable transition. Through this process, gaps within the system were identified and recommendations were provided to address them.

## **CHAPTER 5: CONCLUSION AND RECOMMENDATION**

### **5.1 Introduction**

This thesis aims to study the current KSA-FWM and the role of urban FW in achieving sustainable development. The purpose of this thesis is to assess the role of public awareness and stakeholder interaction with providing recommendations to help minimize the environmental impact of firmware using innovative management practices. This chapter describes the research conclusions, contributions, recommendations, limitations, and future research.

### **5.2 Research conclusion**

This thesis has concluded that FW is managed in an unsustainable way and stakeholders are not adequately prepared to achieve sustainability. Here, the thesis's key findings summarized as follows:

1. This thesis has highlighted on a comprehensive definition of food wastage, as well as a specific definition of food waste, as described in depth in Chapter 2.
2. This thesis has presented the needed of promoting FWM into environmental learning along with practical practices in various sectors such as educational, governmental, and private sectors. There is lack of public knowledge and awareness and the prevailing ambiguity in people's perceptions about FWM as research findings elaborated in section (4.3.1).
3. Currently, KSA-FWM is inefficient due to the large number of FW generated in FSC and the presence of negative practices among KSA stakeholders.

4. There is not a major change or improvement in recent FWM in Saudi's regulations, attitudes, practices, and policies, the economic burden, FW generation, energy and water consumption will continue to increase. As well, food manufacturers and retailers will keep discharging FW without feeling of responsibility or guilt.
5. There is lack of proactive actions towards FWM from government and private sector. Management alternatives in Saudi Arabia are limited to landfill and return to suppliers, with the resulting FW diverted from the retail sector to food manufacturers without any further solutions. In addition to, no appropriate recycling protocols are provided as well.
6. The retail sector is not prepared enough for sustainability as described chapter 4 section (4.2.2.2). Institutional and experts' experiences are insufficient guides to determining how managed FW. In addition to stakeholder perspectives, there is a need to ensure that new policies are fully considered and informed.
7. This research has provided a FWMDT framework for retailers and proposed reactive management solutions for developing KSA-FWM.
8. The FWMDT framework has been implemented in three case studies of food retailers in Saudi Arabia. It's obvious that the FW they generated was poorly managed. Thus, the framework was required to identify the most management option for each type of food.
9. The research modelled 19 factors affecting KSA-FWM by using FCM and set up different simulations and scenarios to aid decision-making.

10. The conclusion of this research demonstrates that there are opportunities to advance the transformation of KSA-FWM towards sustainable development by adopting the recommendations below.

### **5.3 Research contributions**

This dissertation has examined some solutions to develop of FWM practices in the sustainability approach as shown below:

1. Estimation of public awareness and attitudes toward FWM, with provides an integrated environmental approach to detect potential improvements in FWM knowledge and practices.
2. Implementing the FWMDT framework, different types of FW in the retail industry are analyzed through three case studies. The framework demonstrates its practicality and proposes sustainable alternatives for FWM. Beside to provide the potential strength and weakness of the framework.
3. Identification of PESTEL factors that are proposed to influence KSA-FWM. These factors help in designing an FCM platform for all stakeholders.
4. An assessment of relationships among food stakeholders (academic, private sector, and government officials) to model their perspectives, knowledge, and role interactions in the FWM process. Assessments present differences and similarities between roles and ideas to identify stakeholder priorities and conflicts.
5. Scenarios that enhance the performance of the proposed factors (policy actions and green management) are simulated and the future sustainable conditions obtained under each scenario are predicted, aiming to support FWM decision-making.

## 5.4 Recommendations

Here, some recommendations for sustainable FWM:

1. Imposing and prioritizing government policies, regulations, and clear directives and strategies to control FWM processes and actions on the retailers' action and consumption behaviors with analyzing the influence of the current FWM on the economic, nutritional, and environmental cost along the food supply chain and water, energy, and food security nexus and to be prepared for future unforeseen scenarios.
2. Introducing a national strategic plan consistent with FWM should be developed to provide a long-term stable framework that provides the necessary facilities and infrastructure for sustainable FWM. The laws and policies, such as i) mandatory segregation of waste at source leads to cost savings in collection, labor, transportation, and land usage, ii) imposing taxes and fees based on the volume of FW, incentivize the food industry sector and consumers to promote green and sustainable FW alternatives.
3. Each formed policy or strategy should be guaranteed that its objectives will be achieved within a specified time frame and review the results of implementation to decide whether to update or discontinue the policy or strategy.
4. Support stakeholders to engage with universities, research centers and advocate for FWM research and innovation to reach agreements and build partnerships with stakeholders to effectively address FWM priorities and find joint solutions.
5. Establish a holistic and integrated approach (education, government regulation and technology) to increase awareness of sustainable FWM with the aim of motivating individuals to practice to avoid or reduce food waste.

6. Government reforms may involve the adoption of innovative management methods, such as thermal and biological methods for FW processing. For instance, hydrothermal carbonization, ethanol production, anaerobic digestion, mechanical-biological treatment, and composting. In contrast, to common methods such as animal feeding, incineration, and landfills. In addition to reversal strategies, FW treatment focuses on initial source reduction and final stages of landfilling.
7. Promote public-private investment in large-scale utilization of FW for energy production and composting, especially, FW accounts for 40% of solid waste in Saudi Arabia. This aligns with circular economy principles, and budget allocation for FW management is recommended.
8. Cooperation on a global and regional scale, particularly among GCC countries, can help mobilize efforts in preventing FW, contributing to corrective actions collectively.
9. Advocating for the international standardization of food wastage terminologies and classifications is crucial for enhancing global FW management and prevention efforts.

## **5.5 Research limitations**

1. There is a lack of a comprehensive analysis of including all types of FW that assist for establishing sustainable FWM.
2. While the Waste Hierarchy guidelines outline appropriate disposal methods with low environmental and economic impacts, food waste management practices, laws and policies remain a challenge for FWM in the country.
3. Regulatory intervention, participation and collaboration among stakeholders, knowledge gaps, social attitudes, recycling performance and environmental awareness are barriers and limitations to improving FWM sustainability.

4. Many of the technologies proposed in the study with FWM sustainability potential are still unavailable or in the testing phase or economically impractical in the country.
5. Lack of available data and collaboration with food stakeholders. This is a serious issue that may hinder the identification of causes, key influencing factors, environmental and economic impacts, and the development of recommendations for the development of laws and design strategies related to FWM.

## **5.6 Future research**

1. Establish FWM assessment process software for convenient and rapid assessment procedures. The software will generate the most sustainable FWM options relevant to certain food types introduced by the user. It works based on the nine indicators and FWH as previously mentioned in this study. The software should be simple and practical to use since the significant differences between food stakeholders' experiences and visions as obtained in research findings.
2. Initiate a database related to the assessment software FWMDT. To introduce any software, the database needs to be inserted and sorted according to certain standards and concepts before it can be used. The database can be used in Minitab or Excel window, and the evaluation results will display to the user.
3. Examine the applicability of this framework to other types of food and different levels of the food supply chain. In this study, the FWMDT framework was implemented across seven food products and three case studies downstream of FSC (retail sector) with positive results. But further testing is needed across different types of FW and a wider range of food business sector.

4. Modelling and simulation, other multi-variables for prediction new sustainable scenarios. In this study, simulations were performed based on two separate variables. However, further simulations of the different proposed factors previously described in the PESTEL variables are required.
5. Integration an additional alternative into the FWMDT. This research presented five management solutions, which are Redistribution, Animal feeding, Composting, Anaerobic Digestion, and Thermal treatment with energy recovery. The selected solutions have high sustainability performance and are environmentally friendly. On the other hand, more management options would be preferable. For example, using the wormery process, worms consume FW and convert it into fertilizer. Fertilizer can be obtained from worm discharge (casting). In addition to the environmental and economic benefits of the process, earthworms also allow FW to be collected locally and composted before being sent to community gardens.

## 6. References

- Abdullah, N., Al-wesabi, O., Al-Shaibani, B., Alazmi, M., Alsaffar, M., Anbar, M., & Putra, S. (2022). Integrated Approach to Achieve a Sustainable Organic Waste Management System in Saudi Arabia. *Foods*, 11, 1214-1236. doi:10.3390/foods11091214
- Aditya, A., & Kurniawati, K. (2023). Food Waste Management Challenges and Strategies in The Hotel Industry in Jakarta. *Journal of Social Research*, 2(1), 2983-2989. doi:10.55324/josr.v2i9.1295
- Agency. (2015). Hazards from landspreading wastes: Methodology for Rapid Evidence Assessment. *Environment Agency*, 1(1), 1-56. doi:<http://www.gov.uk/government/publications>
- Al-Khateeb, S., Hussain, A., Lange, S., Almutari, M., & Schneider, F. (2021). Battling Food Losses and Waste in Saudi Arabia: Mobilizing Regional Efforts and Blending Indigenous Knowledge to Address Global Food Security Challenges. *Sustainability*, 13(1), 8402-8415. doi:10.3390/su13158402
- Al-Obadi, M., Ayad, H., Pokharel, S., & Ayari, M. (2022). Perspectives on Food Waste Management: Prevention and Social Innovations. *Sustainable Production and Consumption*, 31(1), 190-208. doi:10.1016/j.spc.2022.02.012
- Al-Qahtani, S., Wuhayb, F., Manaa, H., Younis, A., & Sehar, S. (2021). Environmental impact assessment of plastic waste during the outbreak of COVID-19 and integrated strategies for its control and mitigation. *Reviews on Environmental Health*, 37(4), 585-596. doi:10.1515/reveh-2021-0098
- Al-Rumaihi, A., McKay, G., Mackey, H., & Al-Ansari, T. (2020). Environmental Impact Assessment of Food Waste Management Using Two Composting Techniques. *Sustainability*, 12(1), 1595-1618. doi:10.3390/su12041595
- Al-Zahrani, K., & Baig, M. (2014). Food waste in the Kingdom of Saudi Arabia: Need for extension education programs to increase public awareness. *Proceedings of International Academic Conferences*, 1(0200895), 55-56.
- Albizzati, P., Rocchi, P., Cai, M., Tonini, D., & Astrup, T. F. (2022). Rebound effects of food waste prevention: Environmental impacts. *Waste Management*, 153(1), 138-146. doi:10.1016/j.wasman.2022.08.020
- Aldhafeeri, Z., & Alhazmi, H. (2022). Sustainability Assessment of Municipal Solid Waste in Riyadh, Saudi Arabia, in the Framework of Circular Economy Transition. *Sustainability*, 14(9), 5093-5112. doi:10.3390/su14095093

- Alhamdan, A., Hassan, B., Al-Kahtani, H., Younis, M., & Abdelkarim, D. (2016). Quality changes in fresh date fruits (Barhi) during individual quick freezing and conventional slow freezing. *Pakistan Journal of Agricultural Sciences*, 53(4), 917-924. doi:10.21162/PAKJAS/16.4021
- Almalki, S. (2016). Integrating Quantitative and Qualitative Data in Mixed Methods Research—Challenges and Benefits. *Journal of Education and Learning*, 5(3), 288-296. doi:10.5539/jel.v5n3p288
- Almulhim, A. I. (2024). Toward a Greener Future: Applying Circular Economy Principles to Saudi Arabia's Food Sector for Environmental Sustainability. *Sustainability*, 16(2), 786.
- AlQahtani, S., Khan, E., Ahmed, A. E., & A. AlQahtani, M. (2024). Sustainable Management of Food Waste in Saudi Arabia. Food and Nutrition Security in the Kingdom of Saudi Arabia. *Macroeconomic Policy and Its Implication on Food and Nutrition Security*, 2(1), 215-239.
- Alruqaie, I., & Alharbi, B. (2013). Environmental Advantage Assessment of Recycling Food Waste in Riyadh, Saudi Arabia. *Research Journal of Environmental Sciences*, 6(6), 230-237. doi:10.3923/rjes.2012.230.237
- Alsawah, G., Saleh, W., Malibari, A., Lashin, M., & AlGhamdi, T. (2022). Food Waste, Attitudes and Preferences of Young Females: A Case Study in Saudi Arabia. *Sustainability*, 14(4), 1961-1978. doi:10.3390/su14041961
- Alshabanat, Z., Alkhorayef, A., Ben Haddad, H., Imed, M., Gouider, A., Tlili, A., . . . Schmidt, T. (2021). Quantifying Food Loss and Waste in Saudi Arabia. *Sustainability*, 13(16), 9444. doi:10.3390/su13169444
- Alshuwaikhat, H., & Mohammed, I. (2017). Sustainability Matters in National Development Visions—Evidence from Saudi Arabia's Vision for 2030. *Sustainability*, 9(408), 1-15. doi:10.3390/su9030408
- Althumiri, N., Basyouni, M., Duhaim, A., Almousa, N., Aljuwaysim, M., & BinDhim, N. (2021). Understanding Food Waste, Food Insecurity, and the Gap between the Two: A Nationwide Cross-Sectional Study in Saudi Arabia. *Foods*, 10(3), 681-698. doi:10.3390/foods10030681
- Alzaydi, A., Alsolaimani, S., & Ramadan, M. (2013). Demand, practices and properties of compost in the western region of the Kingdom of Saudi Arabia. *Australian Journal of Basic and Applied Sciences*, 7(7), 768-776.

- Amicarelli, V., Lagioia, G., & Bux, C. (2021). Global warming potential of food waste through the life cycle assessment: An analytical review. *Environmental Impact Assessment Review*, 91(8), 1-15. doi:10.1016/j.eiar.2021.106677
- Amrul, N., Ahmad, I., Basri, N., Suja, F., Jalil, N., & Azman, N. (2022). A Review of Organic Waste Treatment Using Black Soldier Fly (*Hermetia illucens*). *Sustainability*, 14(8), 4565. doi:10.3390/su14084565
- Ananno, A., Masud, M., Chowdhury, S., Dabnichki, P., Ahmed, N., & Arefin, A. (2020). Sustainable food waste management model for Bangladesh. *Sustainable Production and Consumption*, 27(1), 35-51. doi:10.1016/j.spc.2020.10.022
- Anjum, M., Miandad, R., Waqas, M., Ahmad, I., Alafif, Z., Aburiazza, A., & Akhtar, T. (2016). Solid waste management in Saudi Arabia. *Applied Agriculture and Biotechnology*, 1(1), 13-26.
- Arvanitoyannis, I. S. (2010). *Waste management for the food industries* (Vol. 1): Academic Press.
- Atkins, P., & Bowler, I. (2016). *Food in society: economy, culture, geography* (Vol. 1): Taylor & Francis Books Limited.
- Ayilara, M., Olanrewaju, O., Babalola, O., & Odeyemi, O. (2020). Waste Management through Composting: Challenges and Potentials. *Sustainability*, 12(11), 4456-4475. doi:10.3390/su12114456
- Baig, M., Al-Zahrani, K., Schneider, F., Straquadine, G., & Mourad, M. (2018). Food waste posing a serious threat to sustainability in the Kingdom of Saudi Arabia – A systematic review. *Saudi Journal of Biological Sciences*, 26(7), 1743-1752. doi:10.1016/j.sjbs.2018.06.004
- Baig, M., Alhafi, B., Alzahrani, K., Pearson, D., Alshammari, G., & Shah, A. (2022). Food Waste in Saudi Arabia: Causes, Consequences, and Combating Measures. *Sustainability*, 14(16), 10362. doi:10.3390/su141610362
- Baig, M., Gorski-Steiner, I., & Neff, R. (2018). Understanding and Addressing Waste of Food in the Kingdom of Saudi Arabia. *Saudi Journal of Biological Sciences*, 26(7), 1633-1648. doi:10.1016/j.sjbs.2018.08.030
- Bandala, E., Liu, A., Wijesiri, B., Zeidman, A., & Goonetilleke, A. (2021). Emerging materials and technologies for landfill leachate treatment: A critical review. *Environmental Pollution*, 291(1), 118133. doi:10.1016/j.envpol.2021.118133
- Barilla, C. (2012). Food Waste: Causes, Impacts and Proposals. Barilla center for food and nutrition, Parma, Emilia-Romagna, Italy. *Barilla*

- center for food and nutrition, Parma, Emilia-Romagna, Italy, 1(1), 1-5.
- Bashraheel, A. (2020). Saudi Arabia Seeks to Vitalize Waste Management Sector. *Arab News*, 1(1), 1-3. doi:<https://arab.news/b56m2>
- Beggio, G., Bonato, T., Schievano, A., Garbo, F., Ciavatta, C., & Pivato, A. (2021). Agricultural application of digestates derived from agricultural and municipal organic wastes: a health risk-assessment for heavy metals. *Journal of Environmental Science and Health, Part A*, 56(13), 1409-1419. doi:10.1080/10934529.2021.2002628
- Beretta, C., & Hellweg, S. (2019). Potential environmental benefits from food waste prevention in the food service sector. *Resources, Conservation and Recycling*, 147(1), 169-178. doi:10.1016/j.resconrec.2019.03.023
- Bernstad Saraiva Schott, A., Vukicevic, S., Bohn, I., & Andersson, T. (2013). Potentials for food waste minimization and effects on potential biogas production through anaerobic digestion. *Waste Management & Research*, 31(8), 811-819. doi:10.1177/0734242x13487584
- Bhuiyan, M. A., Zhang, Q., Xuan, W., Rahman, M. K., & Khare, V. (2023). Does good governance promote sustainable tourism? A systematic review of PESTEL analysis. *SN business & economics*, 3(1), 33-55. doi:10.1007/s43546-022-00408-x
- Bilska, B., Wrzosek, M., Kołożyn-Krajewska, D., & Krajewski, K. (2016). Risk of food losses and potential of food recovery for social purposes. *Waste Management*, 52(1), 269-277. doi:10.1016/j.wasman.2016.03.035
- Bougon, M., Weick, K., & Binkhorst, D. (1977). Cognition in organizations: An analysis of the Utrecht Jazz Orchestra. *Administrative Science Quarterly*, 22(4), 606-639. doi:<https://www.jstor.org/stable/2392403>
- Brunklaus, B., Rex, E., Carlsson, E., & Berlin, J. (2018). The future of Swedish food waste: An environmental assessment of existing and prospective valorization techniques. *Journal of Cleaner Production*, 202(1), 1-10. doi:10.1016/j.jclepro.2018.07.240
- Brunner, P. H., & Rechberger, H. (2015). Waste to energy – key element for sustainable waste management. *Waste Management*, 37(1), 3-12. doi:10.1016/j.wasman.2014.02.003
- Buksti, M., Fremming, T., Juul, S., Grandjean, F., & Christensen, S. (2015). Surplus Food Redistribution System. Feasibility Final Report. In (pp. 7-63): Wageningen, The Netherlands.

- Cakar, B., Aydin, S., Varank, G., & Ozcan, H. K. (2020). Assessment of environmental impact of FOOD waste in Turkey. *Journal of Cleaner Production*, 244(1), 118846. doi:10.1016/j.jclepro.2019.118846
- Canali, M., Amani, P., Aramyan, L., Gheoldus, M., Moates, G., Östergren, K., . . . Vittuari, M. (2017). Food Waste Drivers in Europe, from Identification to Possible Interventions. *Sustainability*, 9(1), 37-49. doi:doi.org/10.3390/su9010037
- Chen, T., Jin, Y., & Shen, D. (2015). A safety analysis of food waste-derived animal feeds from three typical conversion techniques in China. *Waste Management*, 45(1), 42-50. doi:10.1016/j.wasman.2015.06.041
- Chiew, Y. L., Spångberg, J., Baky, A., Hansson, P.-A., & Jönsson, H. (2015). Environmental impact of recycling digested food waste as a fertilizer in agriculture—A case study. *Resources, Conservation and Recycling*, 95(1), 1-14. doi:10.1016/j.resconrec.2014.11.015
- Costa, I., Massard, G., & Agarwal, A. (2010). Waste management policies for industrial symbiosis development: case studies in European countries. *Journal of Cleaner Production*, 18(8), 815-822. doi:10.1016/j.jclepro.2009.12.019
- Creswell, J. (2014). Research design: qualitative, quantitative, and mixed-methods approaches, vol. 1 (1). *Manual Therapy*, 1(1), 1-12.
- Cristóbal, J., Castellani, V., Manfredi, S., & Sala, S. (2018). Prioritizing and optimizing sustainable measures for food waste prevention and management. *Waste Management*, 72(1), 3-16. doi:10.1016/j.wasman.2017.11.007
- Czekała, W., Nowak, M., & Bojarski, W. (2023). Anaerobic digestion and composting as methods of bio-waste management. *Agricultural Engineering*, 27(1), 173-186. doi:10.2478/agriceng-2023-0013
- Davies, R. (2007). Planning policy for retailing. *Retail strategy*, 78-95.
- Debrah, J. K., Vidal, D. G., & Dinis, M. A. P. (2021). Raising Awareness on Solid Waste Management through Formal Education for Sustainability: A Developing Countries Evidence Review. *Recycling*, 6(1), 6-27. doi:doi.org/10.3390/recycling6010006
- Di Talia, E., Simeone, M., & Scarpato, D. (2019). Consumer behaviour types in household food waste. *Journal of Cleaner Production*, 214(1), 166-172. doi:10.1016/j.jclepro.2018.12.216
- Dilkes-Hoffman, L. S., Lane, J. L., Grant, T., Pratt, S., Lant, P. A., & Laycock, B. (2018). Environmental impact of biodegradable food packaging when considering food waste. *Journal of Cleaner Production*, 180(1), 325-334. doi:10.1016/j.jclepro.2018.01.169
- Duret, S., Hoang, H.-M., Derens-Bertheau, E., Delahaye, A., Laguerre, O., & Guillier, L. (2019). Combining Quantitative Risk Assessment of

- Human Health, Food Waste, and Energy Consumption: The Next Step in the Development of the Food Cold Chain? *Risk Analysis*, 39(4), 906-925. doi:<https://doi.org/10.1111/risa.13199>
- Edama. (2021). Our services and products. *Edama Organic Solutions*, 23955, Thuwal, K.S.A. doi:<https://www.edamasolutions.com/>
- Eden, C., Ackermann, F., & Cropper, S. (1992). The Analysis of Cause Maps. *Journal of Management Studies*, 29(3), 309-324. doi:<https://doi.org/10.1111/j.1467-6486.1992.tb00667.x>
- El Bilali, H., & Ben Hassen, T. (2020). Food Waste in the Countries of the Gulf Cooperation Council: A Systematic Review. *Foods*, 9(4), 463-477. doi:[doi.org/10.3390/foods9040463](https://doi.org/10.3390/foods9040463)
- Elshaer, I., Sobaih, A. E. E., Alyahya, M., & Abu Elnasr, A. (2021). The Impact of Religiosity and Food Consumption Culture on Food Waste Intention in Saudi Arabia. *Sustainability*, 13(11), 6473-6489. doi:[10.3390/su13116473](https://doi.org/10.3390/su13116473)
- Emir, O., & Ekici, Ş. Ö. (2023). An integrated assessment of food waste model through intuitionistic fuzzy cognitive maps. *Journal of Cleaner Production*, 418(1), 138061. doi:<https://doi.org/10.1016/j.jclepro.2023.138061>
- EPA. (2004). Landspreading of Organic Waste -Guidance on Groundwater Vulnerability Assessment of Land. doi:[https://www.epa.ie/publications/compliance—enforcement/waste/EPA\\_landspread\\_organic\\_waste\\_guide.pdf](https://www.epa.ie/publications/compliance—enforcement/waste/EPA_landspread_organic_waste_guide.pdf)
- EuropeanCommission. (2015). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. *European Commission*. doi:<https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52015DC0614>
- Falcone, P. M., & De Rosa, S. P. (2020). Use of fuzzy cognitive maps to develop policy strategies for the optimization of municipal waste management: A case study of the land of fires (Italy). *Land Use Policy*, 96(1), 104680. doi:<https://doi.org/10.1016/j.landusepol.2020.104680>
- Falcone, P. M., Lopolito, A., & Sica, E. (2018). The networking dynamics of the Italian biofuel industry in time of crisis: Finding an effective instrument mix for fostering a sustainable energy transition. *Energy Policy*, 112(1), 334-348. doi:<https://doi.org/10.1016/j.enpol.2017.10.036>
- FAO. (1996). Rome Declaration on World Food Security and Plan of Action. doi:<http://www.fao.org/docrep/003/w3613e/w3613e00.htm>.

- FAO. (2011). Global Food Losses and Food Waste - Extent, Causes and Prevention. Rome, Italy. doi:<https://www.fao.org/3/i2697e/i2697e.pdf>.
- FAO. (2013). Food wastage footprint: impacts on natural resources: summary report. *Food & Agriculture Organization of the UN*.
- FAO. (2014). Global Initiative on Food Loss and Waste Reduction: Definitional framework of food loss. SAVE FOOD. doi:<https://www.fao.org/3/at144e/at144e.pdf>.
- FAO. (2017). 9 tips for reducing food waste and becoming a #ZeroHunger hero. doi:<https://www.fao.org/zhc/detail-events/en/c/889172/>.
- FAOUN. (2016). Global initiative on food loss and waste reduction. *Food Save*, 1(1).
- Fareed, S. (2017). Savola and UNEP launch drive to reduce food waste in the Kingdom. Saudi Gazette. doi:[saudigazette.com.sa/article/174890/Savola-and-UNEP-launch-drive-to-reduce-food-waste-in-the-Kingdom](https://saudigazette.com.sa/article/174890/Savola-and-UNEP-launch-drive-to-reduce-food-waste-in-the-Kingdom)
- Fei, X., Jia, W., Chen, T., & Ling, Y. (2021). Life-cycle assessment of two food waste disposal processes based on anaerobic digestion in China. *Journal of Cleaner Production*, 293(1), 126113. doi:<https://doi.org/10.1016/j.jclepro.2021.126113>
- Fellows, R. F., & Liu, A. M. (2021). *Research methods for construction* (Vol. 2): John Wiley & Sons.
- Filimonau, V., & Gherbin, A. (2017). An exploratory study of food waste management practices in the UK grocery retail sector. *Journal of Cleaner Production*, 167(1), 1184-1194. doi:<https://doi.org/10.1016/j.jclepro.2017.07.229>
- Flanagan, K., Robertson, K., & Hanson, C. (2019). Reducing food loss and waste. *Setting the Global Action Agenda: Washington, DC, USA*, 2(2).
- Fleet, G. H., & Mian, M. A. (1987). The occurrence and growth of yeasts in dairy products. *International Journal of Food Microbiology*, 4(2), 145-155. doi:[https://doi.org/10.1016/0168-1605\(87\)90021-3](https://doi.org/10.1016/0168-1605(87)90021-3)
- Gao, A., Tian, Z., Wang, Z., Wennersten, R., & Sun, Q. (2017). Comparison between the Technologies for Food Waste Treatment. *Energy Procedia*, 105(1), 3915-3921. doi:<https://doi.org/10.1016/j.egypro.2017.03.811>
- Garcia-Garcia, G. (2017). Development of a framework for sustainable management of industrial food waste. *Loughborough University*, 1(1), 1-165.
- Garcia-Garcia, G., Woolley, E., & Rahimifard, S. (2015). A framework for a more efficient approach to food waste management. *International*

- Journal of Food Engineering*, 1(1), 65-72. doi:10.18178/ijfe.1.1.65-72
- Garcia-Garcia, G., Woolley, E., Rahimifard, S., Colwill, J., White, R., & Needham, L. (2017). A methodology for sustainable management of food waste. *Waste and biomass valorization*, 8(6), 2209-2227. doi:10.1007/s12649-016-9720-0
- GEO6. (2019). Global environment outlook 6. . *United Nations Educational Program*, 1(1-380). doi:<https://www.unep.org/resources/global-environment-outlook-6>
- Giroto, F., Alibardi, L., & Cossu, R. (2015). Food waste generation and industrial uses: A review. *Waste Management*, 45(1), 32-41. doi:<https://doi.org/10.1016/j.wasman.2015.06.008>
- Giuseppe, A., Mario, E., & Cinzia, M. (2014). Economic benefits from food recovery at the retail stage: An application to Italian food chains. *Waste Management*, 34(7), 1306-1316. doi:<https://doi.org/10.1016/j.wasman.2014.02.018>
- GOV.UK. (2017). Food waste: A response to the policy challenge. UK. doi:[www.gov.uk/go-science](http://www.gov.uk/go-science)
- Gray. (2012). An Introduction to mental modeler: A tool for environmental planning and research. *Mental Modeler Manual*, 1(1), 1-23.
- Gray, C., Clark & Jordan,. . (2012). Modeling the integration of stakeholder knowledge in social-ecological decision-making: Benefits and limitations to knowledge diversity. *Ecological modelling*, 229(1), 88-96.
- Gray, S. A., Gray, S., Cox, L. J., & Henly-Shepard, S. . (2013). Mental modeler: a fuzzy-logic cognitive mapping modeling tool for adaptive environmental management. *46<sup>th</sup> Hawaii international conference on system sciences, IEEE*, 1(1), 965-973.
- Gray, S. A., Zatre, E., & Gray, S. R. (2013). Fuzzy cognitive maps as representations of mental models and group beliefs. In *Fuzzy cognitive maps for applied sciences and engineering: From fundamentals to extensions and learning algorithms. Berlin, Heidelberg: Springer Berlin Heidelberg*, 1(1), 29-48.
- Grizzetti, B., Pretato, U., Lassaletta, L., Billen, G., & Garnier, J. (2013). The contribution of food waste to global and European nitrogen pollution. *Environmental Science & Policy*, 33(1), 186-195.
- Guillard, V., Gaucel, S., Fornaciari, C., Angellier-Coussy, H., Buche, P., & Gontard, N. (2018). The next generation of sustainable food packaging to preserve our environment in a circular economy context. *Frontiers in nutrition*, 5(11), 121-128.
- Gupta, Y., Bhattacharyya, S., & Vlachos, D. G. . (2023). Extraction of valuable chemicals from food waste via computational solvent

- screening and experiments. *Separation and Purification Technology*, 316(1), 123719.
- Guran, S. (2018). Sustainable waste-to-energy technologies: Gasification and pyrolysis. *Sustainable Food Waste-To-energy Systems Sustainability*, 1(1), 141-158.
- Haider, H., AlMarshod, S. Y., AlSaleem, S. S., Ali, A. A. M., Alinizzi, M., Alresheedi, M. T., & Shafiquzzaman, M. (2022). Life cycle assessment of construction and demolition waste Management in Riyadh, Saudi Arabia. *International Journal of Environmental Research and Public Health*, 19(12), 7382.
- Halbrendt, J., Gray, S. A., Crow, S., Radovich, T., Kimura, A. H., & Tamang, B. B. (2014). Differences in farmer and expert beliefs and the perceived impacts of conservation agriculture. *Global Environmental Change*, 28, 50-62.
- Halbrendt, J., Gray, S. A., Crow, S., Radovich, T., Kimura, A. H., & Tamang, B. B. (2014). Differences in farmer and expert beliefs and the perceived impacts of conservation agriculture. *Global Environmental Change*, 28(1), 50-62.
- Hall, K. D., Guo, J., Dore, M., & Chow, C. C. (2009). The progressive increase of food waste in America and its environmental impact. *PloS one*, 4(11), e7940.
- Hanssen, O. J., Ekegren, P., Gram-Hanssen, I., Korpela, P., Langevad-Clifforth, N., Skov-Olsen, K., . . . Svanes, E. (2015). Food Redistribution in the Nordic Region: Experiences and results from a pilot study. *Nordic Council of Ministers*, 1(1), 1-107.
- Haque, M. I., & Khan, M. R. (2022). Impact of climate change on food security in Saudi Arabia: A roadmap to agriculture-water sustainability. *Journal of Agribusiness in Developing and Emerging Economies*, 12(1), 1-18.
- Heng, Y., & House, L. (2022). Consumers' perceptions and behavior toward food waste across countries. *International Food and Agribusiness Management Review*, 25(2), 197-209.
- Henly-Shepard, S., Gray, S. A., & Cox, L. J. (2015). The use of participatory modeling to promote social learning and facilitate community disaster planning. *Environmental Science & Policy*, 45(1), 109-122.
- Hiç, C., Pradhan, P., Rybski, D., & Kropp, J. P. (2016). Food Surplus and Its Climate Burdens. *Environmental Science & Technology*, 50(8), 4269-4277. doi:10.1021/acs.est.5b05088
- Hodge, K. L., Levis, J. W., DeCarolus, J. F., & Barlaz, M. A. (2016). Systematic evaluation of industrial, commercial, and institutional

- food waste management strategies in the United States. *Environmental Science & Technology*, 50(16), 8444-8452.
- Hong, I., Park, S., Lee, B., Lee, J., Jeong, D., & Park, S. (2014). IoT-based smart garbage system for efficient food waste management. *The Scientific World Journal*, 2014(1), 646953. doi:10.1155/2014/646953
- Hoover, D. (2017). Estimating Quantities And Types Of Food Waste At The City Level. *Natural Resources Defense Council*, 1(1). doi: <https://www.fondazionebarilla.com/en/>
- Hox, J. J., & Boeijs, H. R. (2005). Data collection, primary vs. secondary. *Encyclopedia of social measurement*, 1(1), 593-599.
- Huang, C.-H., Liu, S.-M., & Hsu, N.-Y. (2020). Understanding global food surplus and food waste to tackle economic and environmental sustainability. *Sustainability*, 12(7), 2892.
- Hussein, L., Uren, C., Rekik, F., & Hammami, Z. (2022). A review on waste management and compost production in the Middle East-North Africa region. *Waste Management & Research*, 40(8), 1110-1128.
- IGD. (2013). Redistribution to animals. doi:<https://www.igd.com/articles/article-viewer/t/redistribution-to-animals/i/15772>
- Irani, Z., & Sharif, A. M. (2016). Sustainable food security futures: perspectives on food waste and information across the food supply chain. *Journal of Enterprise Information Management*, 29(2), 171-178.
- Irani, Z., Sharif, A. M., Lee, H., Aktas, E., Topaloğlu, Z., van't Wout, T., & Huda, . (2018). Managing food security through food waste and loss: Small data to big data. *Computers & Operations Research*, 29(1), 367-383.
- Isah, S., & Ozbay, G. (2020). Valorization of food loss and wastes: Feedstocks for biofuels and valuable chemicals. *Frontiers in Sustainable Food Systems*, 4(1), 82-97.
- Ismael, R. K. (2023). Quantification of food waste in retail operations: A fruit and vegetable wastage case in Paraguay. *Environmental Challenges*, 10, 100665.
- Jalloun, R. (2022). Knowledge, attitude and awareness of Saudi adults regarding organic food. *African Journal of Food, Agriculture, Nutrition and Development*, 22(1), 19088-19099.
- Jin, Z., Lan, Y., Ohm, J.-B., Gillespie, J., Schwarz, P., & Chen, B. (). . , 104(1), . . (2022). Physicochemical composition, fermentable sugars, free amino acids, phenolics, and minerals in brewers' spent

- grains obtained from craft brewing operations. *Journal of Cereal Science*, 104(1), 103413.
- Johansson, N., & Corvellec, H. (2018). Waste policies gone soft: An analysis of European and Swedish waste prevention plans. *Waste Management*, 77(1), 322-332.
- Jones, N. A., Ross, H., Lynam, T., Perez, P., & Leitch, A. (2011). Mental models: an interdisciplinary synthesis of theory and methods. *Ecology and society*, 16(1), 46-61.
- Jones, R., Speight, R., Blinco, J., & O'Hara, I. (2022). Biorefining within food loss and waste frameworks: A review. *Renewable and Sustainable Energy Reviews*, 154(1), 111781.
- Khan, M. S. M., & Kaneesamkandi, Z (2013). Biodegradable waste to biogas: renewable energy option for the Kingdom of Saudi Arabia. *International Journal of Innovation and Applied Studies*, 4(1), 101-113.
- Khandelwal, H., Thalla, A. K., Kumar, S., & Kumar, R. (2019). Life cycle assessment of municipal solid waste management options for India. *Bioresource technology*, 288(1), 121515.
- Kibler, K. M., Reinhart, D., Hawkins, C., Motlagh, A. M., & Wright, K. (2018). Food waste and the food-energy-water nexus: A review of food waste management alternatives. *Waste Management*, 74(1), 52-62. doi:10.1016/j.wasman.2018.01.014
- Le Mouél, C., Lattre-Gasquet, D., & Mora, J. (2018). Land use and food security in 2050: a narrow road. *1*(1), 1-400.
- Lebron, Y. A. R., Moreira, V. R., Brasil, Y. L., Silva, A. F. R., de Souza Santos, L. V., Lange, L. C., & Amaral, M. C. S. (2021). A survey on experiences in leachate treatment: Common practices, differences worldwide and future perspectives. *Journal of environmental management*, 288(1), 112475.
- Lee, S.-H., Choi, K.-I., Osako, M., & Dong, J.-I. (2007). Evaluation of environmental burdens caused by changes of food waste management systems in Seoul, Korea. *Science of The Total Environment*, 387(3), 42-53.
- Li, Y., Xue, Z., Li, S., Sun, X., & Hao, D. (2023). Prediction of composting maturity and identification of critical parameters for green waste compost using machine learning. *Bioresource technology*, 385(1), 129444.
- Licy, C., Vivek, R., Saritha, K., Anies, T., & Josphina, C. (2013). Awareness, attitude and practice of school students towards household waste management. *Journal of environmental management*, 2(6), 147-150.

- Liu, F., & Liu, Z. (2022). Quantitative evaluation of waste separation management policies in the Yangtze River Delta Based on the PMC index model. *International Journal of Environmental Research and Public Health*, 19(7), 3815.
- Loebnitz, N., & Grunert, K. G. (2015). The effect of food shape abnormality on purchase intentions in China. *Food Quality and Preference*, 40(1), 24-30.
- Maalouf, A., & Mavropoulos, A. . (2023). Re-assessing global municipal solid waste generation. *Waste Management & Research*, 41(4), 936-947.
- MacDonald, N. (1983). Trees and networks in biological models. International System for Agricultural Science and Technology. Chichester (UK) Wiley.
- Mak, T. M., Xiong, X., Tsang, D. C., Iris, K., & Poon, C. S. (2020). Sustainable food waste management towards circular bioeconomy: Policy review, limitations and opportunities. *Bioresource technology*, 297(1), 122497.
- Maria, A. (1997). Introduction to modeling and simulation. *Proceedings of the 29<sup>th</sup> conference on Winter simulation*, 1(1), 7-13.
- Martin-Rios, C., Demen-Meier, C., Gössling, S., & Cornuz, C. (2018). Food waste management innovations in the foodservice industry. *Waste Management*, 79(1), 196-206.
- Martindale, W., & Schiebel, W. (2017). The impact of food preservation on food waste. *British Food Journal*, 119(12), 2510-2518.
- Mehta, C., & Kanak Sirari, K. S. (2018). Comparative study of aerobic and anaerobic composting for better understanding of organic waste management: a mini review. *Plant Archives*, 18(1), 44-48.
- MEWA. (2016). Polices and conditions. doi: <https://www.mewa.gov.sa/en/Ministry/AboutMinistry/RulesAndConditions/Pages/Policy.aspx>
- Mganga, P., Syafrudin, S., & Amirudin, A. (2021). A Survey of Students' Awareness on Food Waste Problems and Their Behaviour towards Food Wastage: A Case Study of Diponegoro University (UNDIP), Indonesia. *E3S Web of Conferences*, 1(1), 1-7.
- Miandad, R., Rehan, M., Ouda, O. K. M., Khan, M. Z., Shahzad, K., Ismail, I. M. I., & Nizami, A. S. (2017). Waste-to-Hydrogen Energy in Saudi Arabia: Challenges and Perspectives. *Biohydrogen Production: Sustainability of Current Technology and Future Perspective New Delhi: Springer India*, 1(1), 237-252.
- Michael. (2017). Feeding catering waste to farmed animals is illegal. . *Animal and Plant Health Agency*, 1(1), 1-10.

- doi:<https://www.gov.uk/government/news/apha-warns-not-to-feed-kitchen-scraps-to-farm-animals-because-of-disease-risk>
- Michellini, L., Principato, L., & Iasevoli, G. (2018). Understanding food sharing models to tackle sustainability challenges. *Ecological Economics*, 145(1), 205-217.
- Mlonka-Mędrala, A., Evangelopoulos, P., Sieradzka, M., Zajemska, M., & Magdziarz, A. (2021). Pyrolysis of agricultural waste biomass towards production of gas fuel and high-quality char: Experimental and numerical investigations. *Fuel*, 120611.
- Moggi, S., Bonomi, S., & Ricciardi, F. (2018). Against food waste: CSR for the social and environmental impact through a network-based organizational model. *Sustainability*, 10(10), 3515.
- Morone, P., Falcone, P. M., & Lopolito, A. (2019). How to promote a new and sustainable food consumption model: A fuzzy cognitive map study. *Journal of cleaner production*, 208(1), 563-574.
- Morone, P., Koutinas, A., Gathergood, N., Arshadi, M., & Matharu, A. (2019). Food waste: Challenges and opportunities for enhancing the emerging bio-economy. *Journal of Cleaner Production*, 221(1), 10-16.
- Morone, P., Yilan, G., & Imbert, E. (2021). Using fuzzy cognitive maps to identify better policy strategies to valorize organic waste flows: An Italian case study. *Journal of cleaner production*, 319(1), 128722.
- Mourad, M., 126(1), . (2016). Recycling, recovering and preventing “food waste”: Competing solutions for food systems sustainability in the United States and France. . *Journal of Cleaner Production*, 126(1), 461-477.
- MRAH. (2019). Ministry of Municipal and Rural Affairs and Housing. doi:<https://momrah.gov.sa/ar>
- Mu, D., Horowitz, N., Casey, M., & Jones, K. (2017). Environmental and economic analysis of an in-vessel food waste composting system at Kean University in the U.S. *Waste Management*, 59(1), 476-486. doi:10.1016/j.wasman.2016.10.026
- Mu’azu, N. D., Blaisi, N. I., Naji, A. A., Abdel-Magid, I. M., & AlQahtany, A. (2019). Food waste management current practices and sustainable future approaches: a Saudi Arabian perspectives. *Journal of Material Cycles and Waste Management*, 21(3), 678-690. doi:10.1007/s10163-018-0808-4.
- Muhammad, F. (2019). Initiative launched to reduce food waste in Saudi Arabia. *Arab News*. doi:<https://www.arabnews.com/node/1600006/saudi-arabia>
- Mukherjee, S. (2011). Policies of retail sector of India and other selected countries. *UTMS Journal of Economics*, 2(2), 171-180.

- Mukhtar, E. M., Williams, I., & Shaw, P. (2017). Visible and invisible factors of solid waste management in developing countries. *16<sup>th</sup> International Waste Management and Landfill Symposium, Cagliari, Italy*, 1(1), 2-6.
- Mumtaz, S., Chu, A. M., Attiq, S., Shah, H. J., & Wong, W.-K. (2022). Habit-Does It Matter? Bringing Habit and Emotion into the Development of Consumer's Food Waste Reduction Behavior with the Lens of the Theory of Interpersonal Behavior. *International Journal of Environmental Research and Public Health*, 19(10), 6312.
- Munir, K. (2022). Sustainable food waste management strategies by applying practice theory in hospitality and food services-a systematic literature review. *Journal of Cleaner Production*, 331(1), 129991.
- Murugesan, K., Srinivasan, K. R., Paramasivam, K., Selvam, A., & Wong, J. (2021). Conversion of Food Waste to Animal Feeds. . *Current Developments in Biotechnology and Bioengineering*, 1(1), 305-324.
- Mutebele, M., Ramasamy, S., Johnson, T., Sivasubramanian, M., Arunachalam, K., Nathan, V. K., & Mukupa,. (2024). Zero-Waste Processes Utilizing Microbes. In *Harnessing Microbial Potential for Multifarious Applications*. *Springer Nature Singapore*, 1(1), 299-321.
- MWAN. (2019). National Center of Waste Management. doi:<https://mwan.gov.sa/>
- Naoum, S. G. (2013). Dissertation research and writing for construction students. *Routledge, Abingdon, Oxon*, 3(1), 1-238.
- Närvänen, E., Mesiranta, N., Mattila, M., & Heikkinen,. (2019). Food waste management: Solving the wicked problem. *Springer Nature Singapore*.
- Neff, R. A., Spiker, M. L., & Truant, P. L. (2015). Wasted food: US consumers' reported awareness, attitudes, and behaviors. *PloS one*, 10(6), e0127881.
- Net. (2023). Waste to Energy. doi:[https://re.emsd.gov.hk/english/energy/thermal/ther\\_faq.html](https://re.emsd.gov.hk/english/energy/thermal/ther_faq.html)
- Nizami, A.-S., Rehan, M., Ouda, O. K., Shahzad, K., Sadeq, Y., Iqbal, T., & Ismail, I. M. (2015). An argument for developing waste-to-energy technologies in Saudi Arabia. *Chemical Engineering*, 45(1), 337-342.
- Nyaki, A., Gray, S. A., Lepczyk, C. A., Skibins, J. C., & Rentsch, D. (2014). Local-scale dynamics and local drivers of bushmeat trade. *Conservation Biology*, 28(5), 1403-1414.

- O'Connor, C., Gheoldus, M., & Jan, O. (2014). Comparative Study on EU Member States' legislation and practices on food donation. *1*(1), 1-29.
- Oelofse, S., Nahman, A., Baig, M. B., Salemdeeb, R., Nizami, A.-S., & Reynolds, C. (2020). Food Waste within South Africa and Saudi Arabia. *Routledge Handbook of Food Waste, New York 10017: Routledge*, *1*(1), 207-224.
- Osimani, A., Garofalo, C., Harasym, J., & Aquilanti, L. . (2022). Use of essential oils against foodborne spoilage yeasts: Advantages and drawbacks. *Current Opinion in Food Science*, *45*(1), 100821.
- Ouda, O. K. M., Raza, S. A., Nizami, A. S., Rehan, M., Al-Waked, R., & Korres, N. E. (2016). Waste to energy potential: A case study of Saudi Arabia. *Renewable and Sustainable Energy Reviews*, *61*(1), 328-340. doi:10.1016/j.rser.2016.04.005
- Özesmi & Özesmi, S. (2003). A participatory approach to ecosystem conservation: fuzzy cognitive maps and stakeholder group analysis in Uluabat Lake, Turkey. *Environmental management*, *31*(1), 0518-0531.
- Özesmi & Özesmi, S. L. (2004). Ecological models based on people's knowledge: a multi-step fuzzy cognitive mapping approach. *Ecological modelling*, *176*(2), 43-64.
- Papageorgiou, E. I., & Salmeron, J. L. (2013). Methods and algorithms for fuzzy cognitive map-based modeling. In *Fuzzy cognitive maps for applied sciences and engineering: from fundamentals to extensions and learning algorithms. Springer Nature, Singapore*, *1*(1), 1-28.
- Papargyropoulou, E., Lozano, R., Steinberger, J. K., Wright, N., & bin Ujang, Z. . (2014). The food waste hierarchy as a framework for the management of food surplus and food waste. *Journal of Cleaner Production*, *76*(1), 106-115.
- Parfitt, J., Stanley, C., & Thompson, L. (2016). Guidance for food and drink manufacturers and retailers on the use of food surplus as animal feed. *Waste and Resource Action Program*, *1*(1), 1-26.
- Paritosh, K., Kushwaha, S. K., Yadav, M., Pareek, N., Chawade, A., & Vivekanand, V. (2017). Food waste to energy: an overview of sustainable approaches for food waste management and nutrient recycling. *BioMed Research International*, *1*(1), 1-19. doi:10.1155/2017/2370927
- Parliament. (2010). Future steps in bio-waste management in the European Union. *European Union*. doi:<https://www.eumonitor.eu/9353000/1/j9vvik7m1c3gyxp/vikqhoczvsub>

- Pasalari, H., Farzadkia, M., Gholami, M., & Emamjomeh, M. M. . (2019). Management of landfill leachate in Iran: valorization, characteristics, and environmental approaches. *Environmental Chemistry Letters*, 17(1), 335-348.
- Pedamkar, P. (2023). Types of Research Methodology. doi:<https://www.educba.com/types-of-research-methodology/>
- Pham, T. P. T., Kaushik, R., Parshetti, G. K., Mahmood, R., & Balasubramanian, R. (2015). Food waste-to-energy conversion technologies: Current status and future directions. *Waste Management*, 38(1), 399-408.
- Pinto, R. S., dos Santos Pinto, R. M., Melo, F. F. S., Campos, S. S., & Cordovil, C. M.-d.-S. (2018). A simple awareness campaign to promote food waste reduction in a University canteen. *Waste Management*, 76(1), 28-38.
- Porter, S. D., Reay, D. S., Higgins, P., & Bomberg, E. (). . , 571,. (2016). A half-century of production-phase greenhouse gas emissions from food loss & waste in the global food supply chain. *Science of The Total Environment*, 571(1), 721-729. doi:10.1016/j.scitotenv.2016.07.041
- Quested, T. E., Marsh, E., Stunell, D., & Parry, A. D. (2013). Spaghetti soup: The complex world of food waste behaviours. *Resources. Conservation and Recycling*, 79, 43-51.
- Radzymińska, M., Jakubowska, D., & Staniewska, K. (2016). Consumer attitude and behaviour towards food waste. *Journal of Agribusiness and Rural Development*, 39(1), 175-181.
- Rashid, M. I., & Shahzad, K. (2021). Food waste recycling for compost production and its economic and environmental assessment as circular economy indicators of solid waste management. *Journal of Cleaner Production*, 317(1), 128467.
- REFED, R. F. W. (2016). A Roadmap to rescue U.S. food waste by 20 percent. doi:[https://refed.org/downloads/ReFED\\_Report\\_2016.pdf](https://refed.org/downloads/ReFED_Report_2016.pdf)
- Rehan, M., Gardy, J., Demirbas, A., Rashid, U., Budzianowski, W. M., Pant, D., & Nizami, A. S. (2018). Waste to biodiesel: A preliminary assessment for Saudi Arabia. *Bioresource technology*, 250(1), 17-25. doi:10.1016/j.biortech.2017.11.024
- Reynolds, C. J., Piantadosi, J., & Boland, J. (2015). Rescuing food from the organics waste stream to feed the food insecure: an economic and environmental assessment of Australian food rescue operations using environmentally extended waste input-output analysis. *Sustainability*, 7(4), 4707-4726.
- Riesenegger, L., & Hübner, A. (2022). Reducing food waste at retail stores- an explorative study. *Sustainability*, 14(5), 2494.

- Rutten, C., Velthuis, A., Steeneveld, W., & Hogeveen, H. (2013). Sensors to support health management on dairy farms. *Journal of dairy science*, 96(4), 1928-1952.
- SA, G. (2016). Saudi Arabia's Vision for 2030. *Government of Saudi Arabia*. doi:<https://www.vision2030.gov.sa/>
- SA, G. (2023). National Platform Environmental Protection, Government of Saudi Arabia. doi:<https://www.my.gov.sa/wps/portal/snp/aboutksa/environmentalProtection>.
- Saer, A., Lansing, S., Davitt, N. H., & Graves, R. E. (2013). Life cycle assessment of a food waste composting system: environmental impact hotspots. *Journal of Cleaner Production*, 52(1), 234-244.
- Saha, P., & Handique, S. (2023). A review on municipal solid wastes and their associated problems and solutions (waste-to-energy recovery and nano-treatment) with special reference to India. *Waste Management and Resource Recycling in the Developing World*, 1(1), 601-623.
- Saint Ville, A. S., Hickey, G. M., & Phillip, L. E. (2017). How do stakeholder interactions influence national food security policy in the Caribbean? The case of Saint Lucia. *Food Policy*, 68(1), 53-64.
- Salemdeeb, R., Zu Ermgassen, E. K., Kim, M. H., Balmford, A., & Al-Tabbaa, A. (2017). Environmental and health impacts of using food waste as animal feed: a comparative analysis of food waste management options. *Journal of Cleaner Production*, 140(1), 871-880.
- Salomone, R., Saija, G., Mondello, G., Giannetto, A., Fasulo, S., & Savastano, D. (2017). Environmental impact of food waste bioconversion by insects: application of life cycle assessment to process using *Hermetia illucens*. *Journal of Cleaner Production*, 140(1), 890-905.
- Sanchez Lopez, J., Patinha Caldeira, C., De Laurentiis, V., Sala, S., & Avraamides, M. (2020). Brief on food waste in the European Union. *European Union*, 1-3.
- Sandell, K. (1996). Sustainability in theory and practice: a conceptual framework of eco-strategies and a case study of low-resource agriculture in the dry zone of Sri Lanka. *Environmental Policy and Society*, 1(1), 163-197.
- Saravanan, A., Karishma, S., Kumar, P. S., & Rangasamy, G. (2023). A review on regeneration of biowaste into bio-products and bioenergy: Life cycle assessment and circular economy. *Fuel*, 338, 127221.

- Saudi Grains Organization, S. (2019). Saudi FLW Baseline: Food Loss & Waste Index in Kingdom of Saudi Arabia. doi:[https://www.sago.gov.sa/Content/Files/Baseline\\_230719.pdf](https://www.sago.gov.sa/Content/Files/Baseline_230719.pdf)
- Savola. (2019). Negaderha. Savola World. doi:<https://negaderha.savolaworld.com/en/story>
- Scherhauser, S., Moates, G., Hartikainen, H., Waldron, K., & Obersteiner, G. (2018). Environmental impacts of food waste in Europe. *Waste Management*, 77(1), 98-113.
- Science, C. (2021). Food & Climate: The Impact of Food on the Environment. doi:<https://climatescience.org>.
- Searchinger, T., Hanson, C., Ranganathan, J., Lipinski, B., Waite, R., Winterbottom, R., . . . Chemineau, P. (2014). Creating a sustainable food future. A menu of solutions to sustainably feed more than 9 billion people by 2050. *World resources report 2013-2014*.
- Segneanu, A.-E., Marin, C. N., Vlase, G., Capan, C., Mihailescu, M., Muntean, C., & Grozescu, I. (2022). Highly efficient engineered waste eggshell-fly ash for cadmium removal from aqueous solution. *Scientific Reports*, 12(1), 1-31.
- SFDA. (2020). Food Hygiene Requirements KSA. doi:<http://www.sFDA.gov.sa/en/regulations/68665>
- Shafiee-Jood, M., & Cai, X. . (2016). Reducing food loss and waste to enhance food security and environmental sustainability. *Environmental Science & Technology*, 8432-8443(50), 16.
- Shah, N. (2000). Probiotic bacteria: selective enumeration and survival in dairy foods. *Journal of dairy science*, 83(4), 894-907.
- Shekdar, A. V. (2009). Sustainable solid waste management: An integrated approach for Asian countries. . *Waste Management*, 29(4), 1438-1448.
- Shore, M., Jordan, P., Melland, A. R., Mellander, P.-E., McDonald, N., & Shortle, G. (2016). Incidental nutrient transfers: assessing critical times in agricultural catchments using high-resolution data. *Science of The Total Environment*, 553(1), 404-415.
- SIRC, C., T. S. I. R., . (2017). Vision 2030. doi:<https://sirc.sa/>
- Son, D., Seo, K., Kim, Y., Lee, J., & Jung, S. P. (2023). Organic waste resource gasification: current status and perspectives. *Journal of Korean Society*, 45(2), 96-106.
- Spang, E. S., Moreno, L. C., Pace, S. A., Achmon, Y., Donis-Gonzalez, I., Gosliner, W. A., . . . Winans, K. S. (). , 44, . (2019). Food loss and waste: measurement, drivers, and solutions. *Annual Review of Environment and Resources*, 44, 117-156.

- Springmann, M., Clark, M., Mason-D'Croz, D., Wiebe, K., Bodirsky, B. L., Lassaletta, L., . . . Carlson, K. M. (2018). Options for keeping the food system within environmental limits. *Nature*, 562(7728), 519-525.
- Stöckli, S., & Dorn, M. (2021). Awareness, intention, and behavior: Three empirical perspectives on predicting the purchase of abnormally shaped fruits and vegetables. *Resources, Conservation and Recycling*, 168(1), 105431.
- Stuart, T. (2009). *Waste: Uncovering the global food scandal*. WW Norton & Company, 1, 87.
- Takata, M., Fukushima, K., Kino-Kimata, N., Nagao, N., Niwa, C., & Toda, T. (2012). The effects of recycling loops in food waste management in Japan: based on the environmental and economic evaluation of food recycling. *Science of The Total Environment*, 432, 309-317.
- Tauringana, V., & Chithambo, L. (2015). The effect of DEFRA guidance on greenhouse gas disclosure. *The British Accounting Review*, 47(4), 425-444.
- Tedesco, D. E. A., Scarioni, S., Tava, A., Panseri, S., & Zuorro, A. (2021). Fruit and vegetable wholesale market waste: safety and nutritional characterisation for their potential re-use in livestock nutrition. *Sustainability*, 9478(13), 16.
- Teigiserova, D. A., Hamelin, L., & Thomsen, M. (2020). Towards transparent valorization of food surplus, waste and loss: Clarifying definitions, food waste hierarchy, and role in the circular economy. *Science of The Total Environment*, 706(1), 136033.
- Thassitou, P., & Arvanitoyannis, I. (2001). Bioremediation: a novel approach to food waste management. *Trends in Food Science & Technology*, 12(6), 185-196.
- Thi, N. B. D., Kumar, G., & Lin, C.-Y. (2015). An overview of food waste management in developing countries: Current status and future perspective. *Journal of environmental management*, 157, 220-229.
- Timmermans, A., Ambuko, J., Belik, W., & Huang, J. (2014). Food losses and waste in the context of sustainable food systems. *CFS Committee on World Food Security*, 1(1), 1-116.
- Tonini, D., Albizzati, P. F., & Astrup, T. F. (2018). Environmental impacts of food waste: Learnings and challenges from a case study on UK. *Waste Management*, 76, 744-766.
- Torok, V. A., Luyckx, K., & Lapidge, S. . (2021). Human food waste to animal feed: opportunities and challenges. *Animal Production Science*, 62(12), 1129-1139.

- UN. (2022). The Sustainable Development Goals Report. *United Nations Educational Program*. doi:<https://sdgs.un.org/goals>.
- UNEP. (2021). UNEP Food Waste Index Report, United Nations Educational Program. doi:[www.unep.org/resources/report/unep-food-waste-index-report-2021](http://www.unep.org/resources/report/unep-food-waste-index-report-2021)
- Union European. (2002). Regulation (EC) No 178/2002 of the European Parliament and of the Council of 28 January 2002. *European Union*. doi:<https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32002R0178>
- Union European. (2023). Food safety, Fact Sheets on the European Union. *European Parliament*. doi:<https://www.europarl.europa.eu/factsheets/en/sheet/51/food-safety>
- Usubiaga, A., Butnar, I., & Schepelmann, P. . (2018). Wasting Food, Wasting Resources: Potential Environmental Savings Through Food Waste Reductions. *Journal of Industrial Ecology*, 22(3), 574-584. doi:10.1111/jiec.12695
- Veugelers, R., & Cassiman, B. (2005). R&D cooperation between firms and universities. Some empirical evidence from Belgian manufacturing. *International Journal of Industrial Organization*, 23(6), 355-379.
- Wang, S., Wang, J., Zhao, S., & Yang, S. (2019). Information publicity and resident's waste separation behavior: An empirical study based on the norm activation model. *Waste Management*, 87(1), 33-42.
- Wang, Y., Yu, G., Xie, S., Jiang, R., Li, C., & Xing, Z. (2023). Pyrolysis of food waste digestate residues for biochar: Pyrolytic properties, biochar characterization, and heavy metal behaviours. *Fuel*, 353, 129185.
- Wang, Y., Yuan, Z., & Tang, Y. (2021). Enhancing food security and environmental sustainability: A critical review of food loss and waste management. *Resources, Environment and Sustainability*, 4(1), 100023.
- Wani, N. R., Rather, R. A., Farooq, A., Padder, S. A., Baba, T. R., Sharma, S., ... & Ara, S. (2024). New insights in food security and environmental sustainability through waste food management. *Environmental Science and Pollution Research*, 31(12), 17835-17857.
- Waqas, M., Almeelbi, T., & Nizami, A.-S. . (2018). Resource recovery of food waste through continuous thermophilic in-vessel composting. *Environmental Science and Pollution Research*, 25(1), 5212-5222.
- Waqas, M., Nizami, A. S., Aburiazaiza, A. S., Barakat, M. A., Rashid, M. I., & Ismail, I. M. I. (2018). Optimizing the process of food waste

- compost and valorizing its applications: A case study of Saudi Arabia. *Journal of Cleaner Production*, 176, 426-438. doi:10.1016/j.jclepro.2017.12.165
- WCED. (1987). Our Common Future. World Commission on Environment and Development. doi:<http://www.un-documents.net/ocf-02.htm>.
- Weis, T. (2013). The meat of the global food crisis. *The Journal of Peasant Studies*, 40(1), 65-85. doi:10.1080/03066150.2012.752357
- WRAP. (2012). Quality Protocol. Compost. End of waste criteria for the production and use of quality compost from source-segregated biodegradable waste. doi:[https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment\\_data/file/297215/geho0812bwpl-e-e.pdf](https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/297215/geho0812bwpl-e-e.pdf)
- WRAP. (2016). Digestate and compost use in agriculture. Good practice guidance for agricultural contractors. doi:<https://wrap.org.uk/sites/default/files/2020-08/WRAP-Digestate-compost-good-practice-guide-reference-version.pdf>
- WWF. (2016). Fight climate change by preventing food waste. *World Wildlife Fund*. doi:<https://www.worldwildlife.org/stories/fight-climate-change-by-preventing-food-waste>
- Xie, Y., Ma, Y., Cai, L., Jiang, S., & Li, C. (2022). Reconsidering meat intake and human health: A review of current research. *Molecular Nutrition & Food Research*, 66(9), 2101066.
- Xue, L., Liu, G., Parfitt, J., Liu, X., Van Herpen, E., Stenmarck, Å., . . . Cheng, S. (2017). Missing Food, Missing Data? A Critical Review of Global Food Losses and Food Waste Data. *Environmental Science & Technology*, 51(12), 6618-6633. doi:10.1021/acs.est.7b00401.
- Zafar, S. (2023). Solid Waste Management in Saudi Arabia. doi:<https://www.ecomena.org/solid-waste-management-in-saudi-arabia/>
- Zahra, K., Farhan, M., Kanwal, A., Sharif, F., Hayyat, M. U., Shahzad, L., & Ghafoor, G. Z. (2023). Investigating the role of bulking agents in compost maturity. *Scientific Reports*, 13(1), 16003.
- Zajonc, O., Frydrych, J., & Jezerska, L. (2014). Pelletization of compost for energy utilization. *IERI Procedia*, 8(1), 2-10.
- Zalengera, C., Blanchard, R. E., Eames, P. C., Juma, A. M., Chitawo, M. L., & Gondwe, K. T. (2014). Overview of the Malawi energy situation and A PESTLE analysis for sustainable development of renewable energy. *Renewable and Sustainable Energy Reviews*, 38(1), 335-347.

- Zhang, N., Williams, I., Kemp, S., & Smith, N. (2011). Greening academia: Developing sustainable waste management at Higher Education Institutions. *Waste Management*, 31(7), 1606-1616.
- Zhang, Z., & Zhao, L. (2019). Voluntary monitoring of households in waste disposal: An application of the institutional analysis and development framework. *Resources, Conservation and Recycling*, 143(1), 45-59.

## 7. Appendices

### Appendix 1: FWM consumer survey

#### Survey on Public Awareness on Food Waste Management إستبانه قياس الوعي العام حول إدارة المخلفات الغذائية

The food waste management is a crucial factor, related to all the activities of food waste: avoiding, reduction, or recycling. Also, it is a tool for decision-making and applying national strategies that can strengthen the country's food waste management practices for a sustainable future. The purpose of this survey is measuring the public awareness about food waste management. Your participation is optional and anonymous, and the survey information will be used for scientific purposes with confidentiality. We kindly ask you to give about 15 minutes or less of your time to complete this questionnaire. Your participation is highly appreciated. This questionnaire is divided into four sections: socio-demographic questions, questions related to awareness of the consequences and impacts of food waste, questions related to knowledge of the food waste management, and questions related to food consumption behavior.

تعد إدارة المخلفات الغذائية عاملاً مهماً ، يتعلق بجميع أنشطة تجنب أو الحد من هدر الطعام أو إعادة تدويره. وأيضاً تعتبر أداة لصنع القرار ووضع خطة وطنية حكيمة لإدارة النفايات الغذائية لمستقبل مستدام. الغرض من هذا الإستبيان هو قياس الوعي العام لدى الناس حول إدارة المخلفات الغذائية. تعتبر المشاركة في ملئ الإستبيان اختياري ويكون ذكر الاسم وتستغرق 15 دقيقة أو أقل، وستعامل البيانات الموجودة في الإستبيان بسرية تامة. شاكرين لكم مشاركتكم فيه . يكون هذا الإستبيان من أربعة أقسام: بيانات عامة، أسئلة تتعلق الوعي بالمخلفات الغذائية على البيئة، أسئلة تتعلق بالمعرفة بإدارة المخلفات الغذائية، أسئلة تتعلق بالممارسات الاستهلاك الغذائي.

\* Indicates required question

#### First : Socio-demographic Characteristics أولاً: معلومات عامة

##### 1. 1-Gender/ الجنس \*

Mark only one oval.

☐ Female أنثى

☐ Male ذكر

2. **2- Age/ العمر \***

Mark only one oval.

- ☐ 18-25  
☐ 26-45  
☐ أكبر من 45 >

3. **3- Educational level/ المستوى التعليمي \***

Mark only one oval.

- ☐ Secondary or Diploma ثانوي أو دبلوم  
☐ Bachelor بكالوريوس  
☐ Postgraduate دراسات عليا

4. **4- Profession/ المهنة \***

Mark only one oval.

- ☐ Student طالب  
☐ Employee موظف  
☐ Freelancer/business owner عاملين لحسابهم الخاص أو صاحب عمل  
☐ Other غير ذلك

5. **5- Marital status/ الحالة الاجتماعية \***

Mark only one oval.

- ☐ Married متزوج  
☐ Unmarried غير متزوج

6. 6- Number of family members including you. عدد أفراد الأسرة بمن فيهم أنت. \*

Mark only one oval.

- ☐ 1-2  
☐ 3-5  
☐ أكثر من 5 More than 5

7. 7- Monthly Income/ الدخل الشهري \*

Mark only one oval.

- ☐ أقل SAR 4999  
☐ SAR 5000-9999  
☐ SAR 10000-14999  
☐ أكثر SAR 15000

8. 8- Nationality / الجنسية \*

Mark only one oval.

- ☐ Saudi سعودي Skip to question 10  
☐ Non-Saudi غير سعودي Skip to question 9

For non-saudi

9. In which country do you live in/ ما هي الدولة التي تعيش فيها \*

\_\_\_\_\_

Skip to question 11

For Saudi

10. \* ما هي المنطقة التي تعيش فيها / In which region do you live in/

Mark only one oval.

- ☐ Northern region المنطقة الشمالية
- ☐ Eastern region المنطقة الشرقية
- ☐ Central region المنطقة الوسطى
- ☐ Western region المنطقة الغربية
- ☐ Southern region المنطقة الجنوبية

Second: Questions related to awareness of consequences and impacts of food waste. أسئلة المتعلقة بالوعي بعواقب وأضرار المخلفات الغذائية على البيئة.

11. \* 9- Food waste is for the planet: المخلفات الغذائية هي لكوكب الأرض

Mark only one oval.

- ☐ A serious problem مشكلة خطيرة
- ☐ A non-serious problem مشكلة غير خطيرة

12. \* 10- Is the food security an issue of concern to you?

هل الأمن الغذائي مسألة تثير قلقك؟

Mark only one oval.

- ☐ Yes نعم
- ☐ No لا

13. \* 11- Do you know the meaning of water footprint? هل تعلم معنى البصمة المائية؟

Mark only one oval.

- ☐ Yes نعم
- ☐ No لا

14. 12- Do you know the meaning of carbon footprint? هل تعلم معنى البصمة الكربونية؟ \*

Mark only one oval.

- ☐ Yes نعم  
☐ No لا

15. 13- Do you know the meaning of ecological footprint? هل تعلم معنى البصمة البيئية؟ \*

Mark only one oval.

- ☐ Yes نعم  
☐ No لا

16. 14- What is the best statement that describes your thoughts on food waste? ما هو أفضل وصف يصف أفكارك حول هدر الطعام؟ \*

Mark only one oval.

- ☐ I think food waste is unavoidable أعتقد أن المخلفات الغذائية أمر لا مفر منه  
☐ I've never considered the problem before, but I plan to change my behavior لم أفكر أبدا في المشكلة من قبل ، لكنني أخطط لتغيير سلوكي  
☐ I'm worried about food waste, and I attempt to avoid it أنا قلق بشأن هدر الطعام ، وأحاول تجنبه

17. 15- How responsible do you think yourself towards food waste ? ما مدى مسؤوليتك تجاه هدر الطعام؟ \*

Mark only one oval.

- |                           |                       |                       |                       |                       |                       |                                 |
|---------------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|---------------------------------|
|                           | 1                     | 2                     | 3                     | 4                     | 5                     |                                 |
| Not responsible غير مسؤول | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | Extremely responsible مسؤول جدا |

18. 16- What do you think is the best practice to reduce food waste? ما هي الطريقة \*  
المتلى للحد من هدر الطعام في رأيك؟

Mark only one oval.

- ☐ Reduce food consumption at source تقليل استهلاك الأغذية من الأساس
- ☐ Make food more expensive رفع أسعار الغذاء
- ☐ Education and awareness التعليم والتوعية
- ☐ Using Social Media networking استخدام شبكات التواصل الاجتماعي
- ☐ Pay taxes and charges on wasted food دفع الضرائب والرسوم على الطعام المهدر
- ☐ Share or donate food مشاركة الطعام أو التبرع به

19. 17- Would you like to be informed about the consequences of food waste and how to reduce it? هل ترغب في أن تكون على معرفة بعواقب المخلفات الغذائية وكيفية الحد منه؟ \*

Mark only one oval.

- ☐ Yes نعم
- ☐ No لا

20. 18- How would you prefer to receive more information? كيف تفضل الحصول على مزيد \*  
من المعلومات؟

Mark only one oval.

- ☐ SMS message رسائل نصية
- ☐ Mobile app تطبيق في الهاتف المحمول
- ☐ Social Media وسائل التواصل الاجتماعي
- ☐ E-mail إيميل
- ☐ TV/radio تلفزيون/ راديو

Third: Questions related to knowledge of the food waste management. الأسئلة  
المتعلقة بالمعرفة بإدارة النفايات الغذائية

21. 19- Do you know where food waste is taken daily and how it is disposed? \*

هل تعرف الى اين يتم اخذ المخلفات الغذائية يوميا وكيفيه التخلص منها؟

Mark only one oval.

☐ Yes نعم

☐ No لا

22. 20- Sorting food waste away from other solid wastes such as plastic and paper is important to take advantage of . \*

فرز المخلفات الغذائية عن غيرها من النفايات . الصلبة كالبلستيك والورق مهم للاستفادة منها

Mark only one oval.

☐ Yes نعم

☐ No لا

☐ Not sure لست متأكدا

23. 21- Using the method of landfill or incineration food waste is an effective way \*  
to dispose of and reduce the volume of waste.

استخدام طريقه ردم او حرق المخلفات الغذائية تعتبر طريقه فعالة لتقليل حجمها والتخلص منها.

Mark only one oval.

☐ Yes نعم

☐ No لا

☐ Not sure لست متأكدا

24. 22- I know what you mean by food waste recycling \*

أعرف معنى تدوير المخلفات الغذائية

Mark only one oval.

☐ Yes نعم

☐ No لا

25. 23- Turning some food leftovers into composting or energy source type of food waste recycling. تحويل بعض بقايا الطعام الى سماد أو مصدر للطاقة من أنواع تدوير المخلفات الغذائية. \*

Mark only one oval.

- ☐ Yes نعم  
☐ No لا  
☐ Not sure لست متأكدًا

26. 24- Food waste management is important to me. يعتبر موضوع إدارة المخلفات الغذائية مهما بالنسبة لي. \*

Mark only one oval.

- ☐ I agree أوافق  
☐ Disagree لاأوافق

27. 25- I think the current way of collecting and managing food waste is appropriate and eco-friendly. أعتقد ان الطريقة المستخدمة حاليا لجمع وإدارة المخلفات الغذائية مناسبة وصديقة للبيئة. \*

Mark only one oval.

- ☐ I agree أوافق  
☐ Disagree لاأوافق  
☐ Not sure لست متأكدًا

28. 26- Eco-friendly food waste management contributes to the sustainable development of the country and highlights it in a beautiful way. إدارة المخلفات الغذائية الصديقة للبيئة يساهم في الوصول للتنمية المستدامة للدولة وإبرازها بصورة جميلة. \*

Mark only one oval.

- ☐ I agree أوافق
- ☐ Disagree لاأوافق
- ☐ Not sure لست متأكدا

29. 27- Food waste management is a shared responsibility between the individual in society and related institutions. إدارة المخلفات الغذائية هي مسؤولية مشتركة بين الفرد في المجتمع والمؤسسات ذات علاقة. \*

Mark only one oval.

- ☐ I agree أوافق
- ☐ Disagree لاأوافق
- ☐ Not sure لست متأكدا

30. 28- School education should be used to raise environmental awareness about the importance of food waste management in society. يجب توظيف المناهج الدراسية لنشر الوعي البيئي حول أهمية إدارة المخلفات الغذائية في المجتمع. \*

Mark only one oval.

- ☐ I agree أوافق
- ☐ Disagree لاأوافق
- ☐ Not sure لست متأكدا

31. 29- Social media networks should be used to spread environmental awareness in society about food waste management and food conservation. \*

يجب استخدام وسائل الإعلام والتواصل الاجتماعي لنشر الوعي البيئي حول إدارة المخلفات الغذائية وثقافة حفظ الطعام في المجتمع.

Mark only one oval.

- ☐ I agree أوافق
- ☐ Disagree لا أوافق
- ☐ Not sure لست متأكدًا

32. 30- I am with applying National Food Waste Management Plan. \*  
انا مع تطبيق خطة وطنية لإدارة المخلفات الغذائية.

Mark only one oval.

- ☐ I agree أوافق
- ☐ Disagree لا أوافق
- ☐ Not sure لست متأكدًا

33. 31- Do you think there is a need for a system or law to identify violations and penalties to prevent food waste in society? \*  
هل ترى من الضروري إصدار نظام أو قانون يحدد المخالفات والعقوبات الرادعة لمنع انتشار المخلفات الغذائية الناتجة عن هدر الطعام في المجتمع؟

Mark only one oval.

- ☐ I agree أوافق
- ☐ Disagree لا أوافق
- ☐ Not sure لست متأكدًا

34. 32- Is it fair to pay fees based on the amount of consumer's food waste generated? هل من العدل دفع رسوم بناءا على كمية النفايات الغذائية الناتجة من المستهلك؟ \*

Mark only one oval.

- ☐ I agree أوافق
- ☐ Disagree لا أوافق
- ☐ Not sure لست متأكدا

35. 33- I am with paying municipal fees for distributing and serving especial smart bins for food waste. أنا مع دفع رسوم بلدية مقابل قيام البلدية بتوزيع حاويات ذكية خاصة للمخلفات الغذائية. \*

Mark only one oval.

- ☐ I agree أوافق
- ☐ Disagree لا أوافق
- ☐ Not sure لست متأكدا

36. 34- I think there is a need to provide citizens and residents with special guidelines for the safe and eco-friendly disposal of food waste. أعتقد أنه من الضروري تزويد المواطنين والمقيمين بأليات إرشادية للتخلص من النفايات الغذائية بطريقة سليمة وصديقة للبيئة. \*

Mark only one oval.

- ☐ I agree أوافق
- ☐ Disagree لا أوافق
- ☐ Not sure لست متأكدا

37. 35- I'm ready to separate the food waste at home from other solid wastes in separate bins if the municipal has asked me to do that. أنا مستعد لفصل المخلفات الغذائية في المنزل عن غيرها من المخلفات الصلبة الأخرى في حاويات منفصلة أن طلبت مني البلدية. \*

Mark only one oval.

- ☐ I agree أوافق
- ☐ Disagree لا أوافق
- ☐ Not sure لست متأكدًا

38. 36- I collect food waste for feeding animals (farms and barns). أقوم بتجميع المخلفات الغذائية لإستخدامها في إطعام الحيوانات (للمزارع والحظائر). \*

Mark only one oval.

- ☐ Always دائما
- ☐ Never أبدا
- ☐ Sometimes أحيانا

39. 37- I collect food waste to turn it into compost for agriculture. أقوم بتجميع المخلفات الغذائية لتحويلها لسماد للزراعة. \*

Mark only one oval.

- ☐ Always دائما
- ☐ Never أبدا
- ☐ Sometimes أحيانا

Fourth: Questions related to food consumption behaviors. الأسئلة المتعلقة بسلوكيات استهلاك الأغذية.

40. 38- How often do you go for grocery shopping? \* كم مرة تذهب لتسوق المواد الغذائية؟

Mark only one oval.

- ☐ Everyday كل يوم
- ☐ Once a week مرة بالأسبوع
- ☐ Twice a week مرتين بالأسبوع
- ☐ Once a month مرة بالشهر

41. 39- How much do you spend on purchasing food monthly? \* كم تنفق على شراء الطعام شهرياً؟

Mark only one oval.

- ☐ Approximately an average of 75% of my income مايقارب متوسط 75% من دخلي
- ☐ Approximately an average of 50% of my income مايقارب متوسط 50% من دخلي
- ☐ Approximately an average of 25% of my income مايقارب متوسط 25% من دخلي
- ☐ Approximately an average of 15% of my income مايقارب متوسط 15% من دخلي

42. 40- Do you use a shopping list at the time of purchase? \* هل تستخدم في وقت الشراء قائمة تسوق؟

Mark only one oval.

- ☐ Yes نعم
- ☐ No لا

43. 41- Do the food special offers attract you? \* هل تجذبك العروض الخاصة على الطعام؟

Mark only one oval.

- ☐ Yes نعم
- ☐ No لا

44. 42- Do you know the difference between 'to be consumed by Best before date' \*  
هل تعرف الفرق بين مصطلحي "الأفضل يستهلك قبل هذا" و "تاريخ انتهاء الصلاحية"؟  
التاريخ و "تاريخ انتهاء الصلاحية"؟

Mark only one oval.

☐ Yes نعم

☐ No لا

45. 43- When you eat out, do you take your leftovers with you? \*  
عندما تأكل خارج المنزل، هل تأخذ المتبقي من الطعام معك؟

Mark only one oval.

☐ Yes نعم

☐ No لا

☐ I would like to, but I do not do it أود ذلك ، لكنني لا أفعل ذلك

46. 44- Do you still discard good food? \*  
هل ما زلت تتخلص من الطعام الجيد؟

Mark only one oval.

☐ Always دائما

☐ Never أبدا

☐ Sometimes أحيانا

47. 45- What is the reason behind you discard the food? Choose all the possibilities ما هو السبب وراء التخلص من الطعام؟ اختر جميع الاحتمالات الممكنة

Check all that apply.

- ☐ The food has not been consumed due to its large packaging لم يتم استهلاك الطعام بسبب الحجم الكبير للعبوة
- ☐ Food has gone bad الطعام أصبح سيئاً
- ☐ Package has been opened for too long عبوة الطعام مفتوحة لفترة طويلة جداً
- ☐ Food purchased in excessive quantities تم شراء الأغذية بكميات زائدة
- ☐ The food has expired انتهت صلاحية الطعام
- ☐ I did not like the food لم يعجبني الطعام
- ☐ Food purchased due to the presence of special offers and not consumed الطعام الذي يتم شراؤه بسبب وجود عروض خاصة ولم يستهلك

48. Notes you'd like to add ملاحظات تود إضافتها

---

Thank you for your participation in this study.

شاكراً لكم مشاركتكم في هذه الدراسة

---

## Appendix 2: FWM retailing sector questionnaire

| Company Information |         |
|---------------------|---------|
| Date                | / /2023 |
| Name                |         |
| Gender              |         |
| Role                |         |
| Area of involvement |         |
| Company             |         |
| Duration            |         |

| Categorization<br>Nine Indicators                                    | The type of food waste |                |                                      |                     |         |       |                |
|----------------------------------------------------------------------|------------------------|----------------|--------------------------------------|---------------------|---------|-------|----------------|
|                                                                      | Fruit and<br>vegetable | Canned<br>food | Dairy<br>products<br>(not<br>drinks) | Meat<br>and<br>fish | Cereals | Bread | Ready<br>meals |
| Edibility                                                            |                        |                |                                      |                     |         |       |                |
| State                                                                |                        |                |                                      |                     |         |       |                |
| Origin                                                               |                        |                |                                      |                     |         |       |                |
| Complexity                                                           |                        |                |                                      |                     |         |       |                |
| Animal-product<br>presence                                           |                        |                |                                      |                     |         |       |                |
| Treatment                                                            |                        |                |                                      |                     |         |       |                |
| Packaging                                                            |                        |                |                                      |                     |         |       |                |
| Packaging<br>biodegradability                                        |                        |                |                                      |                     |         |       |                |
| Stage of the<br>supply chain                                         |                        |                |                                      |                     |         |       |                |
| Current treatment<br>or management                                   |                        |                |                                      |                     |         |       |                |
| Quantity<br>Average amount                                           |                        |                |                                      |                     |         |       |                |
| When and Why<br>does this amount<br>of FW change<br>during the year? |                        |                |                                      |                     |         |       |                |
| Why is this FW<br>generated?                                         |                        |                |                                      |                     |         |       |                |
| Is this FW<br>segregated from<br>other wastes?                       |                        |                |                                      |                     |         |       |                |

### Appendix 3: The nine indicators for categorization food waste.

|   |                                                                            |
|---|----------------------------------------------------------------------------|
| 1 | <b>Edibility</b>                                                           |
|   | - Edible      - Inedible                                                   |
| 2 | <b>State</b>                                                               |
|   | - Eatable      - Uneatable<br>- Uneatable for humans, eatable for animals  |
| 3 | <b>Origin</b>                                                              |
|   | - Animal based      - Plant based                                          |
| 4 | <b>Complexity</b>                                                          |
|   | - Single product      - Mixed product                                      |
| 5 | <b>Animal product presence</b>                                             |
|   | - Meat      - Animal product<br>- Animal by-product (categories 1-3)       |
|   | - In contact with animal products<br>- Not in contact with animal products |
| 6 | <b>Treatment</b>                                                           |
|   | - Processed      - Unprocessed                                             |
| 7 | <b>Packaging</b>                                                           |
|   | - Packaged<br>- Unpackaged / separable from packaging                      |
| 8 | <b>Packaging biodegradability</b>                                          |
|   | - Biodegradable packaging<br>- Non-biodegradable packaging                 |
| 9 | <b>Stage of the supply chain</b>                                           |
|   | - Catering waste      - Non-catering waste                                 |

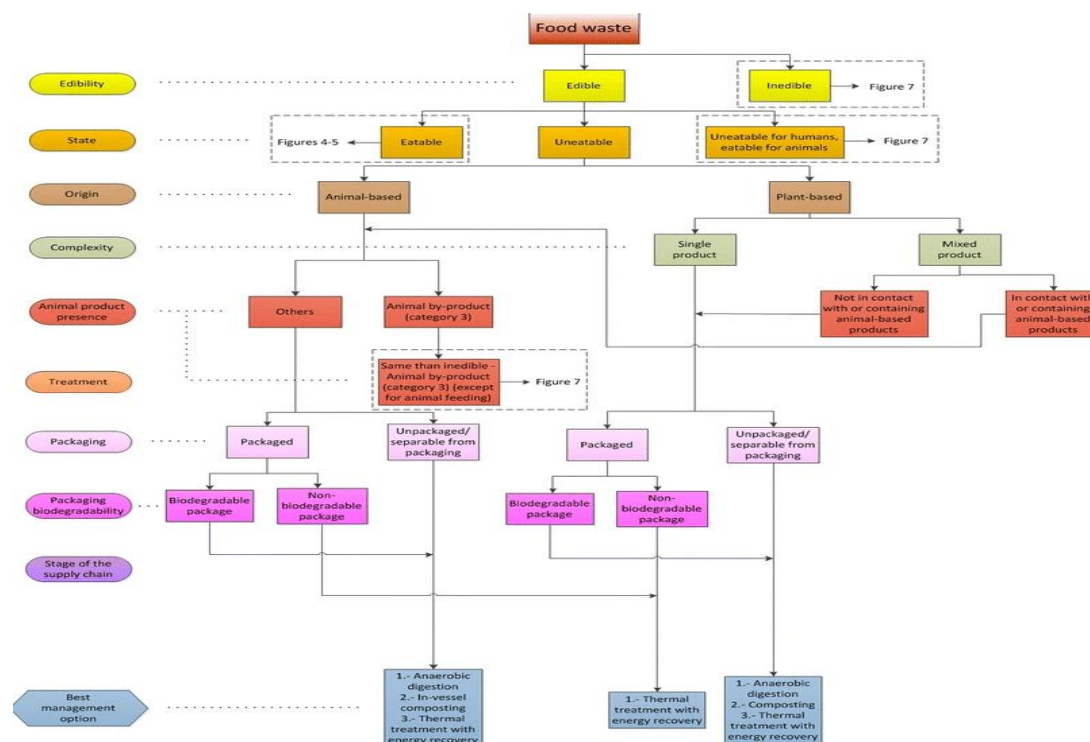
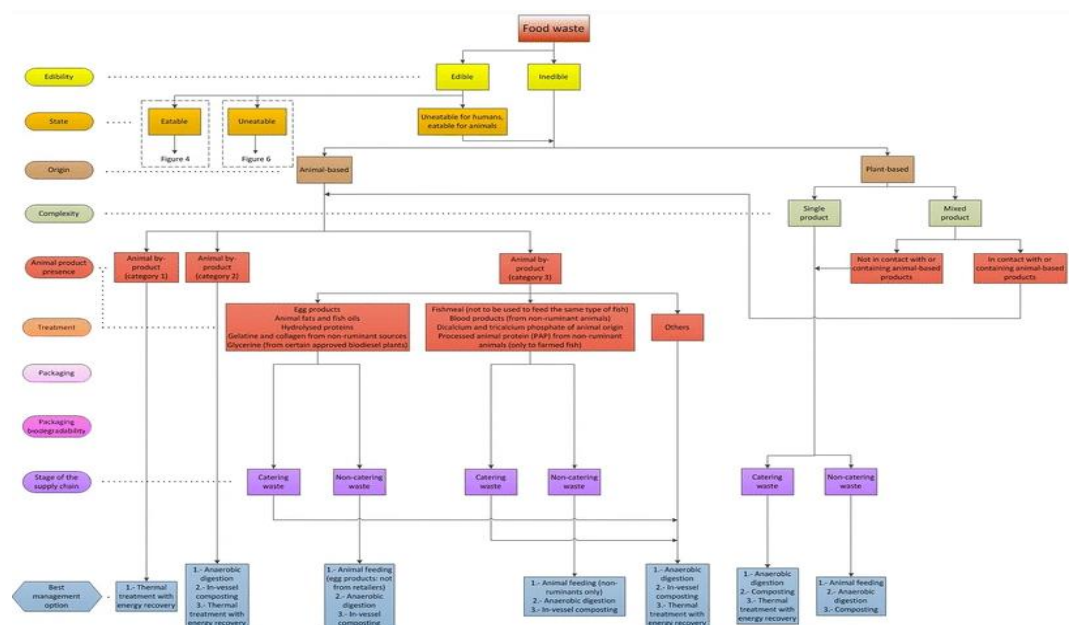
The flowchart classifies food waste based on the following attributes (shown on the left):

- Edibility
- State
- Origin
- Complexity
- Animal product presence
- Treatment
- Packaging
- Packaging biodegradability
- Stage of the supply chain
- Best management option

The classification process is as follows:

- Food waste** is divided into **Edible** and **Inedible**.
  - Inedible** leads to **Figure 7**.
  - Edible** is divided into **Eatable** and **Uneatable**.
    - Uneatable** leads to **Figure 6**.
    - Eatable** is divided into **Animal-based** (leading to **Figure 4**) and **Plant-based**.
- Eatable** (both Animal-based and Plant-based) and **Uneatable** are categorized as **Single product** or **Mixed product**.
- Single product** is divided into **Processed** and **Unprocessed**.
  - Processed** is divided into **Packaged** and **Unpackaged/separable from packaging**.
    - Packaged** is divided into **Biodegradable packages** and **Non-biodegradable packages**.
      - Biodegradable packages** lead to **Best management options**: 1. Redistribution, 2. Thermal treatment with energy recovery.
      - Non-biodegradable packages** lead to **Best management options**: 1. Redistribution, 2. Anaerobic digestion, 3. Composting.
    - Unpackaged/separable from packaging** is divided into **Catering waste** and **Non-catering waste**.
      - Catering waste** leads to **Best management options**: 1. Redistribution, 2. Anaerobic digestion, 3. Composting.
      - Non-catering waste** leads to **Best management options**: 1. Redistribution, 2. Animal feeding (egg products: not from retailers), 3. Anaerobic digestion.
  - Unprocessed** is divided into **Packaged** and **Unpackaged/separable from packaging**.
    - Packaged** is divided into **Biodegradable packages** and **Non-biodegradable packages**.
      - Biodegradable packages** lead to **Best management options**: 1. Anaerobic digestion, 2. Composting, 3. Thermal treatment with energy recovery.
      - Non-biodegradable packages** lead to **Best management options**: 1. Thermal treatment with energy recovery.
    - Unpackaged/separable from packaging** is divided into **Catering waste** and **Non-catering waste**.
      - Catering waste** leads to **Best management options**: 1. Thermal treatment with energy recovery.
      - Non-catering waste** leads to **Best management options**: 1. Animal feeding, 2. Anaerobic digestion, 3. Composting.
- Mixed product** is divided into **Not in contact with or containing meat, animal by-products or raw eggs** and **In contact with or containing meat, animal by-products or raw eggs**.
  - Not in contact with or containing meat, animal by-products or raw eggs** leads to **Processed** or **Unprocessed**.
  - In contact with or containing meat, animal by-products or raw eggs** leads to **Same than Eatable - Animal-based - Meat**, which then leads to **Figure 4**.

[illegible]



## Appendix 6: Indications of mental model structural measurement

| Mental Model Structural Measurement | Description of Measure and Cognitive Inference                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|-------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| N (Concepts)                        | Number of variables included in model; higher number of concepts indicates more components in the mental model (Özesmi and Özesmi 2004)                                                                                                                                                                                                                                                                                                                                                                                                              |
| N (Connections)                     | Number of connections included between variables; higher number of connections indicates higher degree of interaction between components in a mental model (Özesmi and Özesmi 2004)                                                                                                                                                                                                                                                                                                                                                                  |
| N (Transmitter)                     | Components which only have "forcing" functions; indicates number of components that effect other system components but are not affected by others (Eden et al.1992)                                                                                                                                                                                                                                                                                                                                                                                  |
| N (Receiver)                        | Components which have only receiving functions; indicates the number of components that are affected by other system components but have no effect (Eden et al.1992)                                                                                                                                                                                                                                                                                                                                                                                 |
| N (Ordinary)                        | Components with both transmitting and receiving functions; indicates the number of concepts that influence and are influenced by other concepts (Eden et al.1992)                                                                                                                                                                                                                                                                                                                                                                                    |
| Centrality                          | Absolute value of either (a) overall influence in the model (all + and – relationships indicated, for entire model) or (b) influence of individual concepts as indicated by positive (+) or negative (-) values placed on connections between components; indicates (a) the total influence (positive and negative) to be in the system or (b) the conceptual weight/importance of individual concepts (Kosko 1986a). The higher the value, the greater is the importance of all concepts or the individual weight of a concept in the overall model |
| C/N                                 | Number of connections divided by number of variables (concepts). The lower the C/N score, the higher the degree of connectedness in a system (Özesmi and Özesmi 2004)                                                                                                                                                                                                                                                                                                                                                                                |
| Complexity                          | Ratio of receiver variables to transmitter variables. Indicates the degree of resolution and is a measure of the degree to which outcomes of driving forces are considered. Higher complexity indicates more complex systems thinking (Eden et al.1992; Özesmi and Özesmi 2004)                                                                                                                                                                                                                                                                      |
| Density                             | Number of connections compared to number of all possible connections. The higher the density, the more potential management policies exist (Özesmi and Özesmi 2004; Hage and Harary 1983)                                                                                                                                                                                                                                                                                                                                                            |

## Appendix 7: The FCM of the Academia group in matrix form

| ID | Factor                              | P1  | P2  | P3  | P4  | C1  | C2   | C3   | C4  | S1  | S2  | T1  | T2   | T3 | L1  | L2  | E1 | E2 | E3  | E4  |
|----|-------------------------------------|-----|-----|-----|-----|-----|------|------|-----|-----|-----|-----|------|----|-----|-----|----|----|-----|-----|
| P1 | Government policies and laws        | 0   | 0.5 | 0.4 | 0.4 | 0.6 | 0.39 | 0.6  | 0.8 | 0   | 0.4 | 0.5 | 0    | 1  | 0.5 | 0.4 | -1 | -1 | 0   | 0.8 |
| P2 | Collaboration                       | 0   | 0   | 0.5 | 0   | 0.3 | 0.56 | 0.6  | 0.4 | 0   | 0.4 | 0.4 | 0.4  | 0  | 0.4 | 0.3 | -0 | -0 | 0.5 | 0.6 |
| P3 | Public investment in infrastructure | 0.8 | 0.5 | 0   | 0   | 0.6 | 0    | 0.53 | 0.4 | 0   | 0   | 0.5 | 0    | 0  | 0   | 0   | 0  | 0  | 0   | 0.2 |
| P4 | Information campaigns               | 0   | 0   | 0   | 0   | 0   | 0    | 0    | 0.4 | 0.8 | 0   | 0.5 | 0    | 1  | 0   | 0   | -0 | 0  | 0   | 0   |
| C1 | circular economy                    | 0   | 0   | 0   | 0   | 0   | 0    | 0.65 | 0.4 | 0   | 0.6 | 0   | 0    | 0  | 0   | 0   | 0  | 0  | 0   | 0   |
| C2 | Green management                    | 0   | 0.2 | 0   | 0.2 | 0.8 | 0    | 0.47 | 0.7 | 0.3 | 0.6 | 0   | 0    | 1  | 0.6 | 0.4 | -0 | -0 | 0   | 0.5 |
| C3 | Supply chain efficiency             | 0   | 0   | 0   | 0   | 0.6 | 0.46 | 0    | 0.5 | 0   | 0   | 0   | 0    | 0  | 0   | 0   | 0  | 0  | 0   | 0.5 |
| C4 | Economic growth                     | 0   | 0   | 0   | 0   | 0   | 0    | 0.48 | 0   | 0   | 0.6 | 0   | 0.3  | 0  | 0   | 0   | 0  | 0  | 0.3 | -0  |
| S1 | Public awareness                    | 0   | 0   | 0   | 0   | 0.6 | 0.6  | 0    | 0   | 0   | 0   | 0   | 0    | 0  | 0   | 0   | -0 | -0 | -1  | 0.2 |
| S2 | Job opportunities                   | 0   | 0   | 0   | 0   | 0   | 0    | 0    | 0   | 0   | 0   | 0   | 0    | 0  | 0   | 0   | 0  | 0  | 0   | 0.5 |
| T1 | IOT knowledge                       | 0   | 0   | 0   | 0   | 0   | 0    | 0    | 0.5 | 0.7 | 0.5 | 0   | 0    | 1  | 0.4 | 0.4 | -0 | -0 | 0   | 0.5 |
| T2 | Bio-based industry availability     | 0   | 0   | 0.4 | 0   | 0   | 0.36 | 0    | 0.4 | 0   | 0.3 | 0   | 0    | 1  | 0.2 | 0   | -0 | 0  | -1  | 0.5 |
| T3 | R&D activities                      | 0   | 0.4 | 0   | 0   | 0   | 0.41 | 0.55 | 0   | 0.3 | 0   | 0.6 | 0.5  | 0  | 0   | 0   | -0 | -0 | 0   | 0.6 |
| L1 | Relevant FWM laws and regulations   | 0   | 0.4 | 0.3 | 0   | 0   | 0    | 0    | 0   | 0   | 0   | 0   | 0    | 0  | 0   | 0   | 0  | -0 | 0   | 0.5 |
| L2 | International directives            | 0   | 0   | 0   | 0   | 0   | 0.33 | 0    | 0   | 0   | 0   | 0   | 0    | 1  | 0.6 | 0   | 0  | 0  | 0   | 0.5 |
| E1 | Natural resource use                | 0   | 0   | 0   | 0   | 0   | 0    | 0    | -0  | 0   | 0   | 0   | 0    | 0  | 0   | 0   | 0  | 0  | -1  | -1  |
| E2 | Land degradation and contamination  | 0   | 0   | 0   | 0   | 0   | 0    | 0    | -0  | 0   | 0   | 0   | 0    | 0  | 0   | 0   | 0  | 0  | 0   | -1  |
| E3 | Climate change                      | 0   | 0   | 0   | 0   | 0   | 0    | 0    | -0  | 0   | 0   | 0   | -0.5 | 0  | 0   | 0   | -0 | -1 | 0   | -0  |
| E4 | Food security                       | 0   | 0   | 0   | 0   | 0   | 0    | 0    | 0   | 0   | 0   | 0   | 0    | 0  | 0   | 0   | 0  | 0  | 0   | 0   |

## Appendix 8: The FCM of the Academic expert 1 in matrix form

| ID | Factors                             | P1 | P2  | P3  | P4 | C1  | C2   | C3   | C4  | S1 | S2  | T1  | T2   | T3 | L1  | L2  | E1  | E2 | E3   | E4  |
|----|-------------------------------------|----|-----|-----|----|-----|------|------|-----|----|-----|-----|------|----|-----|-----|-----|----|------|-----|
| P1 | Government policies and laws        | 0  | 0.5 | 0.7 | 0  | 0.6 | 0.7  | 0    | 0.6 | 0  | 0.5 | 0.5 | 0    | 0  | 0.5 | 0   | 0   | -1 | 0    | -1  |
| P2 | Collaboration                       | 0  | 0   | 0   | 0  | 0   | 0.23 | 0    | 0   | 0  | 0.4 | 0.4 | 0.4  | 0  | 0   | 0   | 0.4 | 0  | 0    | 0   |
| P3 | Public investment in infrastructure | 0  | 0   | 0   | 0  | 0   | 0    | 0.7  | 0.1 | 0  | 0   | 0.4 | 0    | 0  | 0   | 0   | 0   | 0  | 0    | -1  |
| P4 | Information campaigns               | 0  | 0   | 0   | 0  | 0   | 0    | 0    | 0   | 0  | 0.5 | 0   | 0    | 1  | 0   | 0   | 0   | 0  | 0    | -0  |
| C1 | circular economy                    | 0  | 0   | 0   | 0  | 0   | 0    | 0.65 | 0   | 0  | 0.6 | 0   | 0    | 0  | 0   | 0   | 0   | 0  | 0    | 0   |
| C2 | Green management                    | 0  | 0   | 0   | 0  | 0   | 0    | 0.62 | 0   | 0  | 0   | 0   | 0    | 0  | 0   | 0.4 | 0   | 0  | 0    | 0   |
| C3 | Supply chain efficiency             | 0  | 0   | 0   | 0  | 0.6 | 0    | 0    | 0.5 | 0  | 0   | 0   | 0    | 0  | 0   | 0   | 0   | 0  | 0    | 0   |
| C4 | Economic growth                     | 0  | 0   | 0   | 0  | 0   | 0    | 0    | 0   | 0  | 0   | 0   | 0    | 0  | 0   | 0   | 0   | 0  | 0    | -1  |
| S1 | Public awareness                    | 0  | 0   | 0   | 0  | 0.6 | 0.6  | 0    | 0   | 0  | 0   | 0   | 0    | 0  | 0   | 0   | -0  | -0 | -0.5 | 0.2 |
| S2 | Job opportunities                   | 0  | 0   | 0   | 0  | 0   | 0    | 0    | 0   | 0  | 0   | 0   | 0    | 0  | 0   | 0   | 0   | 0  | 0    | 0.5 |
| T1 | IOT knowledge                       | 0  | 0   | 0   | 0  | 0   | 0    | 0    | 0   | 0  | 0   | 0   | 0    | 1  | 0.4 | 0.4 | 0   | 0  | 0    | 0.5 |
| T2 | Bio-based industry availability     | 0  | 0   | 0.4 | 0  | 0   | 0    | 0    | 0.4 | 0  | 0   | 0   | 0    | 0  | 0   | 0   | -0  | 0  | 0    | 0.5 |
| T3 | R&D activities                      | 0  | 0   | 0   | 0  | 0   | 0    | 0.6  | 0   | 0  | 0   | 0   | 0.5  | 0  | 0   | 0   | -0  | 0  | 0    | 0   |
| L1 | Relevant FWM laws and regulations   | 0  | 0   | 0   | 0  | 0   | 0    | 0    | 0   | 0  | 0   | 0   | 0    | 0  | 0   | 0   | 0   | -0 | 0    | 0.5 |
| L2 | International directives            | 0  | 0   | 0   | 0  | 0   | 0    | 0    | 0   | 0  | 0   | 0   | 0    | 0  | 0.6 | 0   | 0   | 0  | 0    | 0.5 |
| E1 | Natural resource use                | 0  | 0   | 0   | 0  | 0   | 0    | 0    | 0   | 0  | 0   | 0   | 0    | 0  | 0   | 0   | 0   | 0  | 0    | -1  |
| E2 | Land degradation and contamination  | 0  | 0   | 0   | 0  | 0   | 0    | 0    | 0   | 0  | 0   | 0   | 0    | 0  | 0   | 0   | 0   | 0  | 0    | -1  |
| E3 | Climate change                      | 0  | 0   | 0   | 0  | 0   | 0    | 0    | 0   | 0  | 0   | 0   | -0.5 | 0  | 0   | 0   | 0   | 0  | 0    | -1  |
| E4 | Food security                       | 0  | 0   | 0   | 0  | 0   | 0    | 0    | 0   | 0  | 0   | 0   | 0    | 0  | 0   | 0   | 0   | 0  | 0    | 0   |

## Appendix 9: The FCM of the Academic expert 2 in matrix form

| ID | Factors                             | P1 | P2  | P3   | P4   | C1   | C2   | C3  | C4    | S1   | S2   | T1 | T2   | T3 | L1   | L2  | E1    | E2    | E3    | E4   |
|----|-------------------------------------|----|-----|------|------|------|------|-----|-------|------|------|----|------|----|------|-----|-------|-------|-------|------|
| P1 | Government policies and laws        | 0  | 0.7 | 0.02 | 0.41 | 0.38 | 0.56 | 0.5 | 0     | 0.43 | 0.3  | 0  | 0    | 0  | 0.25 | 0.2 | 0     | -0.32 | -0.51 | 0.72 |
| P2 | Collaboration                       | 0  | 0   | 0    | 0    | 0    | 0    | 0   | 0     | 0    | 0    | 0  | 0    | 0  | 0    | 0   | -0.24 | 0     | 0     | 0    |
| P3 | Public investment in infrastructure | 0  | 0   | 0    | 0    | 0    | 0    | 0   | 0     | 0    | 0    | 0  | 0    | 0  | 0    | 0   | 0     | 0     | 0     | 0    |
| P4 | Information campaigns               | 0  | 0   | 0    | 0    | 0    | 0    | 0   | 0.35  | 0.72 | 0    | 0  | 0    | 0  | 0    | 0   | -0.37 | 0     | 0     | 0    |
| C1 | circular economy                    | 0  | 0   | 0    | 0    | 0    | 0    | 0   | 0     | 0    | 0    | 0  | 0    | 0  | 0    | 0   | 0     | 0     | 0     | 0    |
| C2 | Green management                    | 0  | 0   | 0    | 0    | 0    | 0    | 0   | 0     | 0    | 0    | 0  | 0    | 0  | 0    | 0   | 0     | 0     | 0     | 0    |
| C3 | Supply chain efficiency             | 0  | 0   | 0    | 0    | 0    | 0    | 0   | 0     | 0    | 0    | 0  | 0    | 0  | 0    | 0   | 0     | 0     | 0     | 0    |
| C4 | Economic growth                     | 0  | 0   | 0    | 0    | 0    | 0    | 0   | 0     | 0    | 0    | 0  | 0    | 0  | 0    | 0   | 0     | 0     | 0     | 0    |
| S1 | Public awareness                    | 0  | 0   | 0    | 0    | 0    | 0    | 0   | 0     | 0    | 0    | 0  | 0    | 0  | 0    | 0   | 0     | 0     | 0     | 0    |
| S2 | Job opportunities                   | 0  | 0   | 0    | 0    | 0    | 0    | 0   | 0     | 0    | 0    | 0  | 0    | 0  | 0    | 0   | 0     | 0     | 0     | 0    |
| T1 | IOT knowledge                       | 0  | 0   | 0    | 0    | 0    | 0    | 0   | 0     | 0    | 0    | 0  | 0    | 0  | 0    | 0   | 0     | 0     | 0     | 0    |
| T2 | Bio-based industry availability     | 0  | 0   | 0    | 0    | 0    | 0    | 0   | 0     | 0    | 0.31 | 0  | 0    | 0  | 0.5  | 0.2 | 0     | 0     | 0     | 0    |
| T3 | R&D activities                      | 0  | 0   | 0    | 0    | 0    | 0.41 | 0   | 0     | 0    | 0.34 | 0  | 0.36 | 0  | 0    | 0   | 0     | 0     | -0.25 | 0.34 |
| L1 | Relevant FWM laws and regulations   | 0  | 0   | 0    | 0    | 0    | 0    | 0   | 0     | 0    | 0    | 0  | 0    | 0  | 0    | 0   | 0     | 0     | 0     | 0    |
| L2 | International directives            | 0  | 0   | 0    | 0    | 0    | 0.33 | 0   | 0     | 0    | 0    | 0  | 0    | 0  | 0    | 0   | 0     | 0     | 0     | 0    |
| E1 | Natural resource use                | 0  | 0   | 0    | 0    | 0    | 0    | 0   | -0.39 | 0    | 0    | 0  | 0    | 0  | 0    | 0   | 0     | 0     | 0     | 0    |
| E2 | Land degradation and contamination  | 0  | 0   | 0    | 0    | 0    | 0    | 0   | -0.25 | 0    | 0    | 0  | 0    | 0  | 0    | 0   | 0     | 0     | 0     | 0    |
| E3 | Climate change                      | 0  | 0   | 0    | 0    | 0    | 0    | 0   | 0     | 0    | 0    | 0  | 0    | 0  | 0    | 0   | 0     | 0     | 0     | 0    |
| E4 | Food security                       | 0  | 0   | 0    | 0    | 0    | 0    | 0   | 0     | 0    | 0    | 0  | 0    | 0  | 0    | 0   | 0     | 0     | 0     | 0    |

## Appendix 10: The FCM of the Academic expert 3 in matrix

| ID | Factors                             | P1   | P2   | P3   | P4 | C1   | C2   | C3   | C4    | S1   | S2   | T1   | T2   | T3   | L1   | L2  | E1    | E2    | E3    | E4    |
|----|-------------------------------------|------|------|------|----|------|------|------|-------|------|------|------|------|------|------|-----|-------|-------|-------|-------|
| P1 | Government policies and laws        | 0    | 0.4  | 0    | 0  | 0    | 0.5  | 0.5  | 0     | 0    | 0    | 0    | 0    | 0.7  | 0.55 | 0.6 | -0.5  | -0.64 | -0.64 | 0.8   |
| P2 | Collaboration                       | 0    | 0    | 0.47 | 0  | 0.4  | 0.56 | 0.6  | 0.4   | 0    | 0.4  | 0    | 0    | 0    | 0.28 | 0   | -0.51 | -0.34 | 0.51  | 0.57  |
| P3 | Public investment in infrastructure | 0.76 | 0    | 0    | 0  | 0.6  | 0    | 0.36 | 0.64  | 0    | 0    | 0.4  | 0    | 0.37 | 0    | 0   | 0     | 0     | 0     | 0     |
| P4 | Information campaigns               | 0    | 0    | 0    | 0  | 0    | 0    | 0    | 0.43  | 0.9  | 0    | 0    | 0    | 0    | 0    | 0   | 0     | 0     | 0     | 0     |
| C1 | circular economy                    | 0    | 0    | 0    | 0  | 0    | 0    | 0    | 0.36  | 0    | 0.48 | 0    | 0    | 0    | 0    | 0   | 0     | 0     | 0     | 0     |
| C2 | Green management                    | 0    | 0    | 0    | 0  | 0.79 | 0    | 0.47 | 0.7   | 0    | 0.6  | 0    | 0    | 0    | 0    | 0.6 | -0.6  | -0.8  | -0.3  | 0.78  |
| C3 | Supply chain efficiency             | 0    | 0    | 0    | 0  | 0    | 0.46 | 0    | 0     | 0    | 0    | 0    | 0    | 0    | 0    | 0   | 0     | 0     | 0     | 0.45  |
| C4 | Economic growth                     | 0    | 0    | 0    | 0  | 0    | 0    | 0.48 | 0     | 0    | 0.58 | 0    | 0.28 | 0.39 | 0    | 0   | 0     | 0     | 0.33  | 0.29  |
| S1 | Public awareness                    | 0    | 0    | 0    | 0  | 0    | 0    | 0    | 0     | 0    | 0    | 0    | 0    | 0    | 0    | 0   | 0     | 0     | 0     | 0     |
| S2 | Job opportunities                   | 0    | 0    | 0    | 0  | 0    | 0    | 0    | 0     | 0    | 0    | 0    | 0    | 0    | 0    | 0   | 0     | 0     | 0     | 0     |
| T1 | IOT knowledge                       | 0    | 0    | 0    | 0  | 0    | 0    | 0    | 0.5   | 0.69 | 0    | 0    | 0    | 0    | 0    | 0   | -0.3  | -0.21 | -0.34 | 0.46  |
| T2 | Bio-based industry availability     | 0    | 0    | 0    | 0  | 0    | 0.36 | 0    | 0.41  | 0    | 0    | 0    | 0    | 0    | 0    | 0   | 0     | 0     | 0     | 0     |
| T3 | R&D activities                      | 0    | 0.42 | 0    | 0  | 0    | 0    | 0    | 0     | 0    | 0    | 0.85 | 0.71 | 0    | 0    | 0   | 0     | 0     | 0     | 0     |
| L1 | Relevant FWM laws and regulations   | 0    | 0.42 | 0.25 | 0  | 0    | 0    | 0    | 0     | 0    | 0    | 0    | 0    | 0    | 0    | 0   | 0     | 0     | 0     | 0     |
| L2 | International directives            | 0    | 0    | 0    | 0  | 0    | 0    | 0    | 0     | 0    | 0    | 0    | 0    | 0.5  | 0    | 0   | 0     | 0     | 0     | 0     |
| E1 | Natural resource use                | 0    | 0    | 0    | 0  | 0    | 0    | 0    | 0     | 0    | 0    | 0    | 0    | 0    | 0    | 0   | 0     | 0     | -0.46 | -0.49 |
| E2 | Land degradation and contamination  | 0    | 0    | 0    | 0  | 0    | 0    | 0    | 0     | 0    | 0    | 0    | 0    | 0    | 0    | 0   | 0     | 0     | 0     | -0.84 |
| E3 | Climate change                      | 0    | 0    | 0    | 0  | 0    | 0    | 0    | -0.35 | 0    | 0    | 0    | 0    | 0    | 0    | 0   | -0.36 | -0.47 | 0     | -0.48 |
| E4 | Food security                       | 0    | 0    | 0    | 0  | 0    | 0    | 0    | 0     | 0    | 0    | 0    | 0    | 0    | 0    | 0   | 0     | 0     | 0     | 0     |

## Appendix 11: The FCM of the Academic expert 4 in matrix

| ID | Factors                             | P1 | P2  | P3 | P4  | C1  | C2  | C3  | C4 | S1  | S2  | T1  | T2 | T3  | L1  | L2  | E1  | E2    | E3   | E4   |
|----|-------------------------------------|----|-----|----|-----|-----|-----|-----|----|-----|-----|-----|----|-----|-----|-----|-----|-------|------|------|
| P1 | Government policies and laws        | 0  | 0   | 0  | 0   | 0.7 | 0.5 | 0.8 | 1  | 0.2 | 0.5 | 0   | 0  | 0   | 0.7 | 0.3 | 0   | 0     | 0.3  | 0    |
| P2 | Collaboration                       | 0  | 0   | 0  | 0   | 0   | 0   | 0   | 0  | 0   | 0   | 0   | 0  | 0   | 0.4 | 0.6 | 0   | 0     | 0    | 0    |
| P3 | Public investment in infrastructure | 0  | 0.5 | 0  | 0   | 0   | 0   | 0   | 0  | 0   | 0   | 0.6 | 0  | 0   | 0   | 0   | 0   | 0     | 0    | 0.8  |
| P4 | Information campaigns               | 0  | 0   | 0  | 0   | 0   | 0   | 0   | 0  | 0   | 0   | 0   | 0  | 0   | 0   | 0   | 0   | 0     | 0    | 0.5  |
| C1 | circular economy                    | 0  | 0   | 0  | 0   | 0   | 0   | 0   | 0  | 0   | 0   | 0   | 0  | 0   | 0   | 0   | 0   | 0     | 0    | 0    |
| C2 | Green management                    | 0  | 0.2 | 0  | 0.2 | 0   | 0   | 0   | 0  | 0.3 | 0   | 0   | 0  | 0.5 | 0   | 0   | 0.5 | -0.44 | 0    | 0.3  |
| C3 | Supply chain efficiency             | 0  | 0   | 0  | 0   | 0   | 0   | 0   | 0  | 0   | 0   | 0   | 0  | 0   | 0   | 0   | 0   | 0     | 0    | 0    |
| C4 | Economic growth                     | 0  | 0   | 0  | 0   | 0   | 0   | 0   | 0  | 0   | 0   | 0   | 0  | 0   | 0   | 0   | 0   | 0     | 0    | 0    |
| S1 | Public awareness                    | 0  | 0   | 0  | 0   | 0   | 0   | 0   | 0  | 0   | 0   | 0   | 0  | 0   | 0   | 0   | 0   | 0     | 0    | 0    |
| S2 | Job opportunities                   | 0  | 0   | 0  | 0   | 0   | 0   | 0   | 0  | 0   | 0   | 0   | 0  | 0   | 0   | 0   | 0   | 0     | 0    | 0    |
| T1 | IOT knowledge                       | 0  | 0   | 0  | 0   | 0   | 0   | 0   | 0  | 0   | 0.5 | 0   | 0  | 0   | 0   | 0   | 0   | 0     | 0    | 0.6  |
| T2 | Bio-based industry availability     | 0  | 0   | 0  | 0   | 0   | 0   | 0   | 0  | 0   | 0   | 0   | 0  | 0   | 0   | 0   | 0   | 0     | -0.5 | 0.4  |
| T3 | R&D activities                      | 0  | 0   | 0  | 0   | 0   | 0   | 0.5 | 0  | 0.3 | 0   | 0.5 | 0  | 0   | 0   | 0   | 0   | -0.44 | 0    | 0.8  |
| L1 | Relevant FWM laws and regulations   | 0  | 0   | 0  | 0   | 0   | 0   | 0   | 0  | 0   | 0   | 0   | 0  | 0   | 0   | 0   | 0   | 0     | 0    | 0    |
| L2 | International directives            | 0  | 0   | 0  | 0   | 0   | 0   | 0   | 0  | 0   | 0   | 0   | 0  | 0   | 0   | 0   | 0   | 0     | 0    | 0    |
| E1 | Natural resource use                | 0  | 0   | 0  | 0   | 0   | 0   | 0   | 0  | 0   | 0   | 0   | 0  | 0   | 0   | 0   | 0   | 0     | -0.6 | 0    |
| E2 | Land degradation and contamination  | 0  | 0   | 0  | 0   | 0   | 0   | 0   | 0  | 0   | 0   | 0   | 0  | 0   | 0   | 0   | 0   | 0     | 0    | -0.6 |
| E3 | Climate change                      | 0  | 0   | 0  | 0   | 0   | 0   | 0   | 0  | 0   | 0   | 0   | 0  | 0   | 0   | 0   | 0   | 0     | 0    | 0    |
| E4 | Food security                       | 0  | 0   | 0  | 0   | 0   | 0   | 0   | 0  | 0   | 0   | 0   | 0  | 0   | 0   | 0   | 0   | 0     | 0    | 0    |

## Appendix 12: The FCM of the retail group in matrix for

| ID | Factors                             | P1  | P2   | P3  | P4 | C1 | C2   | C3   | C4   | S1   | S2   | T1   | T2   | T3 | L1   | L2   | E1   | E2    | E3   | E4   |
|----|-------------------------------------|-----|------|-----|----|----|------|------|------|------|------|------|------|----|------|------|------|-------|------|------|
| P1 | Government policies and laws        | 0   | 0.41 | 0.6 | 0  | 0  | 0.42 | 0.53 | 0    | 0.4  | 0    | 0    | 0.5  | 0  | 0.45 | 0.35 | 0    | 0     | 0    | 0.36 |
| P2 | Collaboration                       | 0   | 0    | 0   | 0  | 0  | 0.18 | 0    | 0    | 0    | 0    | 0.24 | 0    | 0  | 0    | 0    | 0    | 0     | 0    | 0.4  |
| P3 | Public investment in infrastructure | 0   | 0    | 0   | 0  | 0  | 0    | 0    | 0.07 | 0    | 0    | 0    | 0.26 | 0  | 0    | 0    | 0    | 0     | 0    | 0    |
| P4 | Information campaigns               | 0   | 0    | 0   | 0  | 0  | 0    | 0    | 0    | 0.34 | 0    | 0    | 0    | 0  | 0    | 0    | 0    | -0.24 | -0.4 | 0.26 |
| C1 | circular economy                    | 0   | 0    | 0   | 0  | 0  | 0    | 0    | 0    | 0    | 0.46 | 0    | 0    | 0  | 0    | 0    | 0    | 0     | 0    | 0    |
| C2 | Green management                    | 0   | 0    | 0   | 0  | 0  | 0    | 0    | 0    | 0    | 0    | 0    | 0.5  | 0  | 0    | 0    | 0    | 0.27  | -0.5 | 0.35 |
| C3 | Supply chain efficiency             | 0   | 0    | 0   | 0  | 0  | 0    | 0    | 0    | 0    | 0    | 0.46 | 0    | 0  | 0    | 0    | -0.5 | -0.5  | -0.3 | 0    |
| C4 | Economic growth                     | 0   | 0    | 0   | 0  | 0  | 0    | 0    | 0    | 0    | 0.3  | 0    | 0    | 0  | 0    | 0    | 0    | 0     | 0    | 0    |
| S1 | Public awareness                    | 0   | 0    | 0   | 0  | 0  | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0  | 0    | 0    | 0    | 0     | 0    | 0.14 |
| S2 | Job opportunities                   | 0   | 0    | 0   | 0  | 0  | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0  | 0    | 0    | 0    | 0     | 0    | 0    |
| T1 | IOT knowledge                       | 0   | 0    | 0   | 0  | 0  | 0    | 0    | 0.31 | 0.21 | 0    | 0    | 0    | 0  | 0    | 0    | 0    | 0     | 0    | 0    |
| T2 | Bio-based industry availability     | 0   | 0    | 0   | 0  | 0  | 0    | 0    | 0.47 | 0    | 0    | 0    | 0    | 0  | 0    | 0    | 0    | 0     | 0    | 0    |
| T3 | R&D activities                      | 0   | 0    | 0   | 0  | 0  | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0  | 0    | 0.15 | 0    | -0.24 | 0    | 0    |
| L1 | Relevant FWM laws and regulations   | 0   | 0    | 0   | 0  | 0  | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0  | 0    | 0    | 0    | 0     | 0    | 0    |
| L2 | International directives            | 0.2 | 0    | 0   | 0  | 0  | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0  | 0    | 0    | 0    | 0     | 0    | 0    |
| E1 | Natural resource use                | 0   | 0    | 0   | 0  | 0  | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0  | 0    | 0    | 0    | 0     | 0    | 0    |
| E2 | Land degradation and contamination  | 0   | 0    | 0   | 0  | 0  | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0  | 0    | 0.33 | 0    | 0     | 0    | 0    |
| E3 | Climate change                      | 0   | 0    | 0   | 0  | 0  | 0    | -0.4 | 0    | 0    | 0    | 0    | 0    | 0  | 0    | 0    | 0    | 0     | 0    | 0    |
| E4 | Food security                       | 0   | 0    | 0   | 0  | 0  | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0  | 0    | 0    | 0    | 0     | 0    | 0    |

## Appendix 13: The FCM of the retail expert 5 in matrix form

| ID | Factors                             | P1  | P2   | P3  | P4 | C1 | C2   | C3 | C4   | S1   | S2   | T1   | T2  | T3 | L1  | L2   | E1 | E2    | E3   | E4   |
|----|-------------------------------------|-----|------|-----|----|----|------|----|------|------|------|------|-----|----|-----|------|----|-------|------|------|
| P1 | Government policies and laws        | 0   | 0.53 | 0.6 | 0  | 0  | 0.48 | 0  | 0    | 0.4  | 0    | 0    | 0.5 | 0  | 0.6 | 0    | 0  | 0     | 0    | 0    |
| P2 | Collaboration                       | 0   | 0    | 0   | 0  | 0  | 0    | 0  | 0    | 0    | 0    | 0    | 0   | 0  | 0   | 0    | 0  | 0     | 0    | 0    |
| P3 | Public investment in infrastructure | 0   | 0    | 0   | 0  | 0  | 0    | 0  | 0    | 0    | 0    | 0    | 0   | 0  | 0   | 0    | 0  | 0     | 0    | 0    |
| P4 | Information campaigns               | 0   | 0    | 0   | 0  | 0  | 0    | 0  | 0    | 0.29 | 0    | 0    | 0   | 0  | 0   | 0    | 0  | -0.35 | -0.4 | 0.26 |
| C1 | circular economy                    | 0   | 0    | 0   | 0  | 0  | 0    | 0  | 0    | 0    | 0.47 | 0    | 0   | 0  | 0   | 0    | 0  | 0     | 0    | 0    |
| C2 | Green management                    | 0   | 0    | 0   | 0  | 0  | 0    | 0  | 0    | 0    | 0    | 0    | 0   | 0  | 0   | 0    | 0  | 0     | 0    | 0    |
| C3 | Supply chain efficiency             | 0   | 0    | 0   | 0  | 0  | 0    | 0  | 0    | 0    | 0    | 0.46 | 0   | 0  | 0   | 0    | 0  | 0     | 0    | 0    |
| C4 | Economic growth                     | 0   | 0    | 0   | 0  | 0  | 0    | 0  | 0    | 0    | 0    | 0    | 0   | 0  | 0   | 0    | 0  | 0     | 0    | 0    |
| S1 | Public awareness                    | 0   | 0    | 0   | 0  | 0  | 0    | 0  | 0    | 0    | 0    | 0    | 0   | 0  | 0   | 0    | 0  | 0     | 0    | 0    |
| S2 | Job opportunities                   | 0   | 0    | 0   | 0  | 0  | 0    | 0  | 0    | 0    | 0    | 0    | 0   | 0  | 0   | 0    | 0  | 0     | 0    | 0    |
| T1 | IOT knowledge                       | 0   | 0    | 0   | 0  | 0  | 0    | 0  | 0.31 | 0    | 0    | 0    | 0   | 0  | 0   | 0    | 0  | 0     | 0    | 0    |
| T2 | Bio-based industry availability     | 0   | 0    | 0   | 0  | 0  | 0    | 0  | 0.47 | 0    | 0    | 0    | 0   | 0  | 0   | 0    | 0  | 0     | 0    | 0    |
| T3 | R&D activities                      | 0   | 0    | 0   | 0  | 0  | 0    | 0  | 0    | 0    | 0    | 0    | 0   | 0  | 0   | 0    | 0  | 0     | 0    | 0    |
| L1 | Relevant FWM laws and regulations   | 0   | 0    | 0   | 0  | 0  | 0    | 0  | 0    | 0    | 0    | 0    | 0   | 0  | 0   | 0    | 0  | 0     | 0    | 0    |
| L2 | International directives            | 0.2 | 0    | 0   | 0  | 0  | 0    | 0  | 0    | 0    | 0    | 0    | 0   | 0  | 0   | 0    | 0  | 0     | 0    | 0    |
| E1 | Natural resource use                | 0   | 0    | 0   | 0  | 0  | 0    | 0  | 0    | 0    | 0    | 0    | 0   | 0  | 0   | 0    | 0  | 0     | 0    | 0    |
| E2 | Land degradation and contamination  | 0   | 0    | 0   | 0  | 0  | 0    | 0  | 0    | 0    | 0    | 0    | 0   | 0  | 0   | 0.33 | 0  | 0     | 0    | 0    |
| E3 | Climate change                      | 0   | 0    | 0   | 0  | 0  | 0    | 0  | 0    | 0    | 0    | 0    | 0   | 0  | 0   | 0    | 0  | 0     | 0    | 0    |
| E4 | Food security                       | 0   | 0    | 0   | 0  | 0  | 0    | 0  | 0    | 0    | 0    | 0    | 0   | 0  | 0   | 0    | 0  | 0     | 0    | 0    |

## Appendix 14: The FCM of the retail expert 6 in matrix form

| ID | Factors                             | P1 | P2 | P3 | P4 | C1   | C2 | C3   | C4   | S1   | S2   | T1 | T2 | T3 | L1  | L2   | E1   | E2    | E3 | E4   |
|----|-------------------------------------|----|----|----|----|------|----|------|------|------|------|----|----|----|-----|------|------|-------|----|------|
| P1 | Government policies and laws        | 0  | 0  | 0  | 0  | 0.25 | 0  | 0    | 0    | 0    | 0    | 0  | 0  | 0  | 0.3 | 0.35 | 0    | 0     | 0  | 0.36 |
| P2 | Collaboration                       | 0  | 0  | 0  | 0  | 0.18 | 0  | 0    | 0    | 0    | 0    | 0  | 0  | 0  | 0   | 0    | 0    | 0     | 0  | 0.4  |
| P3 | Public investment in infrastructure | 0  | 0  | 0  | 0  | 0    | 0  | 0.07 | 0    | 0    | 0    | 0  | 0  | 0  | 0   | 0    | 0    | 0     | 0  | 0    |
| P4 | Information campaigns               | 0  | 0  | 0  | 0  | 0    | 0  | 0    | 0.11 | 0    | 0    | 0  | 0  | 0  | 0   | 0    | 0    | -0.13 | 0  | 0    |
| C1 | circular economy                    | 0  | 0  | 0  | 0  | 0    | 0  | 0    | 0    | 0    | 0    | 0  | 0  | 0  | 0   | 0    | 0    | 0     | 0  | 0    |
| C2 | Green management                    | 0  | 0  | 0  | 0  | 0    | 0  | 0    | 0    | 0    | 0    | 0  | 0  | 0  | 0   | 0    | 0.29 | 0     | 0  | 0    |
| C3 | Supply chain efficiency             | 0  | 0  | 0  | 0  | 0    | 0  | 0    | 0    | 0    | 0    | 0  | 0  | 0  | 0   | 0    | -0.5 | -0.5  | 0  | 0    |
| C4 | Economic growth                     | 0  | 0  | 0  | 0  | 0    | 0  | 0    | 0    | 0    | 0.27 | 0  | 0  | 0  | 0   | 0    | 0    | 0     | 0  | 0    |
| S1 | Public awareness                    | 0  | 0  | 0  | 0  | 0    | 0  | 0    | 0    | 0    | 0    | 0  | 0  | 0  | 0   | 0    | 0    | 0     | 0  | 0.14 |
| S2 | Job opportunities                   | 0  | 0  | 0  | 0  | 0    | 0  | 0    | 0    | 0    | 0    | 0  | 0  | 0  | 0   | 0    | 0    | 0     | 0  | 0    |
| T1 | IOT knowledge                       | 0  | 0  | 0  | 0  | 0    | 0  | 0    | 0    | 0.21 | 0    | 0  | 0  | 0  | 0   | 0    | 0    | 0     | 0  | 0    |
| T2 | Bio-based industry availability     | 0  | 0  | 0  | 0  | 0    | 0  | 0    | 0    | 0    | 0    | 0  | 0  | 0  | 0   | 0    | 0    | 0     | 0  | 0    |
| T3 | R&D activities                      | 0  | 0  | 0  | 0  | 0    | 0  | 0    | 0    | 0    | 0    | 0  | 0  | 0  | 0   | 0.15 | 0    | 0     | 0  | 0    |
| L1 | Relevant FWM laws and regulations   | 0  | 0  | 0  | 0  | 0    | 0  | 0    | 0    | 0    | 0    | 0  | 0  | 0  | 0   | 0    | 0    | 0     | 0  | 0    |
| L2 | International directives            | 0  | 0  | 0  | 0  | 0    | 0  | 0    | 0    | 0    | 0    | 0  | 0  | 0  | 0   | 0    | 0    | 0     | 0  | 0    |
| E1 | Natural resource use                | 0  | 0  | 0  | 0  | 0    | 0  | 0    | 0    | 0    | 0    | 0  | 0  | 0  | 0   | 0    | 0    | 0     | 0  | 0    |
| E2 | Land degradation and contamination  | 0  | 0  | 0  | 0  | 0    | 0  | 0    | 0    | 0    | 0    | 0  | 0  | 0  | 0   | 0    | 0    | 0     | 0  | 0    |
| E3 | Climate change                      | 0  | 0  | 0  | 0  | 0    | 0  | -0.4 | 0    | 0    | 0    | 0  | 0  | 0  | 0   | 0    | 0    | 0     | 0  | 0    |
| E4 | Food security                       | 0  | 0  | 0  | 0  | 0    | 0  | 0    | 0    | 0    | 0    | 0  | 0  | 0  | 0   | 0    | 0    | 0     | 0  | 0    |

## Appendix 15: The FCM of the retail expert 7 in matrix form

| ID | Factors                             | P1   | P2   | P3 | P4 | C1 | C2   | C3   | C4   | S1   | S2   | T1   | T2   | T3 | L1   | L2 | E1   | E2    | E3   | E4   |
|----|-------------------------------------|------|------|----|----|----|------|------|------|------|------|------|------|----|------|----|------|-------|------|------|
| P1 | Government policies and laws        | 0    | 0.29 | 0  | 0  | 0  | 0.53 | 0.53 | 0    | 0    | 0    | 0    | 0    | 0  | 0    | 0  | 0    | 0     | 0    | 0    |
| P2 | Collaboration                       | 0    | 0    | 0  | 0  | 0  | 0    | 0    | 0    | 0    | 0    | 0.24 | 0    | 0  | 0    | 0  | 0    | 0     | 0    | 0    |
| P3 | Public investment in infrastructure | 0    | 0    | 0  | 0  | 0  | 0    | 0    | 0    | 0    | 0    | 0    | 0.26 | 0  | 0    | 0  | 0    | 0     | 0    | 0    |
| P4 | Information campaigns               | 0    | 0    | 0  | 0  | 0  | 0    | 0    | 0    | 0.63 | 0    | 0    | 0    | 0  | 0    | 0  | 0    | 0     | 0    | 0    |
| C1 | circular economy                    | 0    | 0    | 0  | 0  | 0  | 0    | 0    | 0.42 | 0    | 0.45 | 0    | 0    | 0  | 0.23 | 0  | 0    | 0     | 0    | 0    |
| C2 | Green management                    | 0    | 0    | 0  | 0  | 0  | 0    | 0    | 0    | 0    | 0    | 0    | 0.5  | 0  | 0    | 0  | 0.25 | 0     | -0.3 | 0.35 |
| C3 | Supply chain efficiency             | 0    | 0    | 0  | 0  | 0  | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0  | 0    | 0  | 0    | 0     | -0.5 | 0    |
| C4 | Economic growth                     | 0    | 0    | 0  | 0  | 0  | 0    | 0    | 0    | 0    | 0.33 | 0    | 0    | 0  | 0    | 0  | 0    | 0     | 0    | 0    |
| S1 | Public awareness                    | 0    | 0    | 0  | 0  | 0  | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0  | 0    | 0  | 0    | 0     | 0    | 0    |
| S2 | Job opportunities                   | 0    | 0    | 0  | 0  | 0  | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0  | 0    | 0  | 0    | 0     | 0    | 0    |
| T1 | IOT knowledge                       | 0    | 0    | 0  | 0  | 0  | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0  | 0    | 0  | 0    | 0     | 0    | 0    |
| T2 | Bio-based industry availability     | 0    | 0    | 0  | 0  | 0  | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0  | 0    | 0  | 0    | 0     | 0    | 0    |
| T3 | R&D activities                      | 0    | 0    | 0  | 0  | 0  | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0  | 0    | 0  | 0    | -0.24 | 0    | 0    |
| L1 | Relevant FWM laws and regulations   | 0    | 0    | 0  | 0  | 0  | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0  | 0    | 0  | 0    | 0     | 0    | 0    |
| L2 | International directives            | 0.43 | 0    | 0  | 0  | 0  | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0  | 0    | 0  | 0    | 0     | 0    | 0    |
| E1 | Natural resource use                | 0    | 0    | 0  | 0  | 0  | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0  | 0    | 0  | 0    | 0     | 0    | 0    |
| E2 | Land degradation and contamination  | 0    | 0    | 0  | 0  | 0  | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0  | 0    | 0  | 0    | 0     | 0    | 0    |
| E3 | Climate change                      | 0    | 0    | 0  | 0  | 0  | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0  | 0    | 0  | 0    | 0     | 0    | 0    |
| E4 | Food security                       | 0    | 0    | 0  | 0  | 0  | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0  | 0    | 0  | 0    | 0     | 0    | 0    |

## Appendix 16: The FCM of the official expert 8 in matrix form

| ID | Factors                             | P1 | P2   | P3   | P4   | C1   | C2   | C3  | C4 | S1  | S2   | T1  | T2   | T3   | L1   | L2   | E1   | E2    | E3   | E4   |
|----|-------------------------------------|----|------|------|------|------|------|-----|----|-----|------|-----|------|------|------|------|------|-------|------|------|
| P1 | Government policies and laws        | 0  | 0.7  | 0    | 0    | 0    | 0.6  | 0   | 0  | 0   | 0    | 0   | 0    | 0    | 0.43 | 0.56 | 0    | 0     | 0    | 0    |
| P2 | Collaboration                       | 0  | 0    | 0    | 0.4  | 0    | 0    | 0   | 0  | 0   | 0    | 0   | 0    | 0.53 | 0    | 0    | 0    | 0     | 0    | 0    |
| P3 | Public investment in infrastructure | 0  | 0.35 | 0    | 0    | 0    | 0    | 0   | 0  | 0   | 0    | 0   | 0    | 0    | 0    | 0    | 0    | 0     | -0.5 | 0    |
| P4 | Information campaigns               | 0  | 0    | 0    | 0    | 0.4  | 0.55 | 0.2 | 0  | 0.5 | 0    | 0   | 0    | 0    | 0    | 0    | 0    | 0     | 0    | 0    |
| C1 | circular economy                    | 0  | 0    | 0    | 0    | 0    | 0    | 0   | 0  | 0   | 0.4  | 0   | 0    | 0    | 0    | 0    | 0    | 0     | 0    | 0    |
| C2 | Green management                    | 0  | 0    | 0.2  | 0    | 0.81 | 0    | 0   | 0  | 0   | 0    | 0.5 | 0    | 0    | 0    | 0    | 0    | -0.57 | 0    | 0.39 |
| C3 | Supply chain efficiency             | 0  | 0    | 0    | 0    | 0    | 0    | 0   | 0  | 0   | 0    | 0   | 0.54 | 0.57 | 0    | 0    | 0    | 0     | 0    | 0    |
| C4 | Economic growth                     | 0  | 0    | 0    | 0    | 0.73 | 0.41 | 0   | 0  | 0   | 0.49 | 0   | 0    | 0    | 0    | 0    | 0.61 | 0     | 0    | 0    |
| S1 | Public awareness                    | 0  | 0    | 0    | 0    | 0    | 0    | 0   | 0  | 0   | 0    | 0   | 0    | 0    | 0    | 0    | 0    | 0     | 0    | 0    |
| S2 | Job opportunities                   | 0  | 0    | 0    | 0    | 0    | 0    | 0   | 0  | 0   | 0    | 0   | 0    | 0    | 0    | 0    | 0    | 0     | 0    | 0    |
| T1 | IOT knowledge                       | 0  | 0    | 0    | 0    | 0    | 0.39 | 0   | 0  | 0   | 0    | 0   | 0    | 0    | 0    | 0    | 0    | 0     | 0    | 0    |
| T2 | Bio-based industry availability     | 0  | 0    | 0    | 0    | 0    | 0    | 0   | 0  | 0   | 0    | 0   | 0    | 0    | 0    | 0    | 0    | -0.3  | 0    | 0    |
| T3 | R&D activities                      | 0  | 0    | 0.51 | 0    | 0    | 0    | 0   | 0  | 0   | 0    | 0   | 0    | 0    | 0    | 0    | 0    | 0     | 0    | 0    |
| L1 | Relevant FWM laws and regulations   | 0  | 0    | 0    | 0    | 0    | 0.5  | 0   | 0  | 0   | 0    | 0   | 0    | 0    | 0    | 0    | 0    | 0     | 0    | 0    |
| L2 | International directives            | 0  | 0.71 | 0    | 0.62 | 0    | 0    | 0   | 0  | 0   | 0    | 0   | 0    | 0    | 0    | 0    | 0    | 0     | 0.6  | 0    |
| E1 | Natural resource use                | 0  | 0    | 0    | 0    | 0    | 0    | 0   | 0  | 0   | 0    | 0   | 0    | 0    | 0    | 0    | 0    | 0     | 0    | 0    |
| E2 | Land degradation and contamination  | 0  | 0    | 0    | 0    | 0    | 0    | 0   | 0  | 0   | 0    | 0   | 0    | 0    | 0    | 0    | -0.3 | 0     | 0    | 0    |
| E3 | Climate change                      | 0  | 0    | 0    | 0    | 0.48 | 0    | 0   | 0  | 0   | 0    | 0   | 0    | 0    | 0    | 0    | 0    | 0     | 0    | 0    |
| E4 | Food security                       | 0  | 0    | 0    | 0    | 0.45 | 0    | 0   | 0  | 0   | 0    | 0   | 0    | 0    | 0    | 0    | 0    | 0     | 0    | 0    |

## Appendix 17: The CFCM of Community in matrix form

| ID | Factors                             | P1   | P2   | P3   | P4   | C1   | C2   | C3   | C4    | S1   | S2   | T1   | T2   | T3   | L1   | L2   | E1    | E2    | E3    | E4    |
|----|-------------------------------------|------|------|------|------|------|------|------|-------|------|------|------|------|------|------|------|-------|-------|-------|-------|
| P1 | Government policies and laws        | 0    | 0.54 | 0.48 | 0.41 | 0.56 | 0.49 | 0.56 | 0.8   | 0.4  | 0.44 | 0.54 | 0.5  | 0.7  | 0.46 | 0.45 | -0.5  | -0.53 | -0.28 | 0.58  |
| P2 | Collaboration                       | 0    | 0    | 0.47 | 0.4  | 0.27 | 0.37 | 0.6  | 0.4   | 0    | 0.4  | 0.32 | 0.4  | 0.53 | 0.4  | 0.28 | -0.1  | -0.34 | -0.4  | 0.48  |
| P3 | Public investment in infrastructure | 0.76 | 0.42 | 0    | 0    | 0.6  | 0    | 0.53 | 0.22  | 0    | 0    | 0.46 | 0.26 | 0.37 | 0    | 0    | 0     | 0     | -0.5  | 0.15  |
| P4 | Information campaigns               | 0    | 0    | 0    | 0    | 0.4  | 0.55 | 0.2  | 0.39  | 0.55 | 0    | 0.5  | 0    | 0.62 | 0    | 0    | -0.37 | 0.24  | -0.4  | 0.14  |
| C1 | circular economy                    | 0    | 0    | 0    | 0    | 0    | 0    | 0.65 | 0.36  | 0    | 0.47 | 0    | 0    | 0    | 0    | 0    | 0     | 0     | 0     | 0     |
| C2 | Green management                    | 0    | 0.2  | 0.2  | 0.2  | 0.8  | 0    | 0.47 | 0.7   | 0.3  | 0.6  | 0.5  | 0.5  | 0.5  | 0.6  | 0.4  | -0.05 | -0.2  | -0.3  | 0.42  |
| C3 | Supply chain efficiency             | 0    | 0    | 0    | 0    | 0.57 | 0.46 | 0    | 0.45  | 0    | 0    | 0.46 | 0.54 | 0.57 | 0    | 0    | -0.5  | -0.5  | -0.5  | 0.45  |
| C4 | Economic growth                     | 0    | 0    | 0    | 0    | 0.73 | 0.41 | 0.48 | 0     | 0    | 0.45 | 0    | 0.28 | 0.39 | 0    | 0    | 0.61  | 0     | 0.33  | -0.36 |
| S1 | Public awareness                    | 0    | 0    | 0    | 0    | 0.6  | 0.6  | 0    | 0     | 0    | 0    | 0    | 0    | 0    | 0    | 0    | -0.46 | -0.4  | -0.5  | 0.18  |
| S2 | Job opportunities                   | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0     | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0     | 0     | 0     | 0.5   |
| T1 | IOT knowledge                       | 0    | 0    | 0    | 0    | 0    | 0.39 | 0    | 0.4   | 0.43 | 0.5  | 0    | 0    | 0.5  | 0.4  | 0.4  | -0.3  | -0.21 | -0.34 | 0.53  |
| T2 | Bio-based industry availability     | 0    | 0    | 0.4  | 0    | 0    | 0.36 | 0    | 0.44  | 0    | 0.31 | 0    | 0    | 0.5  | 0.2  | 0    | -0.3  | -0.3  | -0.5  | 0.45  |
| T3 | R&D activities                      | 0    | 0.42 | 0    | 0    | 0    | 0.41 | 0.55 | 0     | 0.3  | 0    | 0.56 | 0.52 | 0    | 0    | 0.15 | 0.44  | -0.34 | -0.25 | 0.57  |
| L1 | Relevant FMM laws and regulations   | 0    | 0.42 | 0.25 | 0    | 0    | 0.5  | 0    | 0     | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0     | -0.41 | 0     | 0.5   |
| L2 | International directives            | 0.2  | 0.71 | 0    | 0.62 | 0    | 0.33 | 0    | 0     | 0    | 0    | 0    | 0    | 0.5  | 0.6  | 0    | 0     | 0     | 0     | 0.49  |
| E1 | Natural resource use                | 0    | 0    | 0    | 0    | 0    | 0    | 0    | -0.39 | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0     | 0     | -0.53 | -0.54 |
| E2 | Land degradation and contamination  | 0    | 0    | 0    | 0    | 0    | 0    | 0    | -0.25 | 0    | 0    | 0    | 0    | 0    | 0    | 0.33 | -0.3  | 0     | 0     | -0.7  |
| E3 | Climate change                      | 0    | 0    | 0    | 0    | 0.48 | 0    | -0.4 | -0.35 | 0    | 0    | 0    | -0.5 | 0    | 0    | 0    | -0.36 | -0.47 | 0     | -0.49 |
| E4 | Food security                       | 0    | 0    | 0    | 0    | 0.45 | 0    | 0    | 0     | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0     | 0     | 0     | 0     |

## Appendix 18: Journal paper

### Chapter 10 Sustainable Management of Food Waste in Saudi Arabia



Shahrah S. AlQahtani, Ezzat Khan, Adam E. Ahmed,  
and Meshabbab A. AlQahtani

**Abstract** Food waste management, FWM is essential factor that is firmly related to environment and creates several issues throughout the globe. Food waste, FW is a global threatening subject for food systems. Because of inadequate infrastructure and techniques, many countries are facing difficulties in judicious management of FW. Comprehensive definition of the term “food wastage” (Food Waste, Food loss, and food surplus) with clear classification (Avoidable, Nonavoidable, unplanned, planned food waste and post-harvest food waste) is elaborated. It helps to distinguish wasted food at all stages of food supply chain (FSC), which needs to be addressed and managed. Likewise, a brief discussion about Saudi Arabia (among the top food wasters) is included and some of the challenges that may cause the gaps in

---

S. S. AlQahtani (✉)

Department of Environment and Sustainable Development, College of Science, University of Bahrain, Sakhir 32038, Kingdom of Bahrain  
e-mail: [shahrah\\_saad@outlook.sa](mailto:shahrah_saad@outlook.sa); [202012465@stu.uob.edu.bh](mailto:202012465@stu.uob.edu.bh)

E. Khan

Department of Chemistry, College of Science, University of Bahrain, Sakhir 32038, Kingdom of Bahrain

Department of Chemistry, University of Malakand, Chakdara, Lower Dir 18800, Khyber Pakhtunkhwa, Pakistan

E. Khan

e-mail: [ezkhan@uob.edu.bh](mailto:ezkhan@uob.edu.bh)

A. E. Ahmed

Department of Agribusiness and Consumer Sciences, College of Agricultural and Food Sciences, King Faisal University, Al-Ahsa 31982, Saudi Arabia  
e-mail: [ayassin@kfu.edu.sa](mailto:ayassin@kfu.edu.sa); [adamelhag2002@yahoo.com](mailto:adamelhag2002@yahoo.com)

Department of Agricultural Economics, Faculty of Agriculture, University of Khartoum, Khartoum, Sudan

M. A. AlQahtani

Independent Researcher, Khobar 34715, Saudi Arabia  
e-mail: [meshabbab@outlook.com](mailto:meshabbab@outlook.com); [meshabbab@hotmail.com](mailto:meshabbab@hotmail.com)

© The Author(s), under exclusive license to Springer Nature Switzerland AG 2024 215  
A. E. Ahmed et al. (eds.), *Food and Nutrition Security in the Kingdom of Saudi Arabia*,  
Vol. 2, [https://doi.org/10.1007/978-3-031-46704-2\\_10](https://doi.org/10.1007/978-3-031-46704-2_10)

the management have also been discussed in some specific cases. The potential environmental impacts of food waste and its treatment techniques have also been highlighted to identify gaps and hotspots in food waste management. Besides, the article suggests some strategies to tackle food loss/waste by applying zero hunger strategy, sustainable management, legislations and strict laws, and circular bioeconomy. Also, some recommendations to strengthen the role of food waste management has been addressed at the end.

**Keywords** Environmental impacts · Food waste · Food loss · Sustainable management · Zero hunger

## 1 Introduction

Food waste is one of the major environmental issues and unstructured problem because of stranded circumstances of identifying the causes and effects of the subject issue (Närvänen, Mesiranta, Mattila, and Heikkinen 2019). According to Food and Agriculture Organization (FAO) more than 850 million people globally could not access to their needed food. An estimated amount, 1.3 billion tons of food is wasted annually, causing a huge loss of USD 900 billion to global economy (Mirza B Baig, Al-Zahrani, Schneider, Straquadine, and Mourad, 2019a, b). Food waste occurs at various stages of FSC, depending upon the situation, available facilities, locality/country, and management. It can be post-harvested, during transportation, during storage or at the end of the FSC. There seems to be a terminology problem to define food wastage. Many authors have attempted to address the issue, (FAO 2011; Huang et al. 2020) and they consider food loss is occurring at primary stage of FSC during post-harvest processing of agricultural products before retail. However, it becomes more serious in terms of price when considered at the end of the FSC during retail and consumption (Corrado et al. 2019; Huang et al. 2020). In developed countries like Germany, Italy, US, Japan and several other, more than 40% of food is wasted at the retail and consumption stages which is enough to cover three times the globe's hunger. On the other hand, in developing countries most of the food wastage occurs at the post-harvest and processing stages due to limited resources (Huang et al. 2020; Xue et al. 2017). Continuous efforts have been made to create awareness in the society to prevent food waste, it reveals that in 2007 the food waste estimate was 11.6 million tons, and it was reduced to 10 Mt in 2015 (FAO 2017). Whereas, till 2025 food waste is estimated to rise annually which means recent regulations and policies are not enough or practical to reduce the food waste to reach food security and sustainability. Some authors have classified food loss and waste, based on edibility or inedibility, avoidability or unavoidable (Närvänen et al. 2019). Understanding the definitions based on edible and inedible parts of the food may help the decision-makers to implement appropriate processes and strategies to improve the role of food wastage management (Corrado et al. 2019).

The total municipal wastage in Saudi Arabia is produced from the three main cities Riyadh, Jeddah and Dammam is 40% of the total (Bashraheel 2020). The food wastage harms the environment, it also destructively affects the natural resources such as land, energy and water that have been used during the food production (Grizzetti et al. 2013). Furthermore, it is authentically linked to health problems such as obesity, diabetic, and hypertension issues which reaches 59.4%, 23.9%, and 40.5%, respectively of Saudi's population. The Saudi's officials encourage and increase the waste recycling up to 42% with reducing 82% of the overall waste divert to landfills (Bashraheel 2020). Under the umbrella of Saudi's vision 2030, food wastage management team is working hard to setup doable standards and procedures for sustainability and catch up the rest of devoted countries to protect the earth (Bashraheel 2020).

The purpose of this study is, to propose comprehensive definition of food waste and loss and discuss adverse effects of food loss/waste on environment and natural ecosystem. Moreover, it provides different strategies and some future recommendations to overcome FW/L and enhance the FWM. The graphical framework and the key element of the entire study is summarized in Fig. 1.



**Fig. 1** The schematic representation of main topics covered in this study. Constructed by the Author

## 2 Food Wastage, a Controversy in Its Definition

There is a controversy in definitions of various terms related to food waste, the matter has not been seriously considered except from a very recent report (Teigiserova et al. 2020). The food waste varies in how to be managed in many countries due to unclear food waste terminology, and it is challenging to compare all the systematic research results of food waste (Huang et al. 2020). On the basis of lack of clear definition, the sustainable management of food—waste is somewhat difficult. The abovementioned reports cover the topic in a comprehensive way and six categories of food have been elaborated, namely, (i) edible, (ii) naturally inedible, (iii) industrial residue, (iv) inedible due to natural causes, (v) inedible due to ineffective management and (vi) not accounted for (Teigiserova et al. 2020). These six categories reorder the food wastage hierarchy to support a circular bioeconomy depending on whether the food can be consumed or not. Category 1 surplus food, includes all edible food, is the greatest choice for both source protection and human consumption (reuse) in FWM. Source protection and human consumption are best served by this method; category II-V food waste includes all inedible food for any cause or any reason at all: bones, leaves, pomace, crops that have been damaged or neglected and it prioritize for biorefinery and recycling (compost, animal feed etc.) as the environmental option in food wastage pyramid; and category VI food losses that is disposed to landfills or incineration as the least preferable option in the pyramid (Teigiserova et al. 2020). If wastage of food is categorized into specific groups, it makes the food wastage analysis straightforward to improve and monitor wastage management. Globally, there is a major gap in the recognition and classification of terms like food loss, food waste, and food surplus which is wasted or lost over half of the produced food before and after it reaches human consumption. The FAO defines food loss as, “any decrease in the amount of food in the food supply chain”. Not all food wastage can be considered food loss, it refers to the food that is intended for human consumption but is not properly consumed. It's not obvious, when food loss becomes waste (FAO 2014; Isah and Ozbay 2020; Kibler et al. 2018). The following section describes various terminology of food wastage generation. The food wastage is classified into three main and common terms regarding to the food supply chain (FSC): (i) food surplus, (ii) food waste includes (avoidable and non-avoidable) and (iii) food loss includes (planned, unplanned, and post-harvest) which are elaborated as below.

### 2.1 Food Surplus

It is the amount of food made available or produced in excess of the people needs and demand. It reflects an overproduction of food in agricultural processes or represents the extra amounts of imported agricultural products through the government organizations. Post-harvest, oversupply, and inedible foods are wastage channels before reaching to suppliers and consumers and is considered the food surplus category as

well. Further, food production can be changed in some circumstances and from year to year according to the climate and economics effects that include market prices impacting farmers' choices of crops. However, food surplus may help offset the food deficits and enhance achieving the food security. It is considered a laudable achievement because of reaching a level of food security to community needs, and it can accommodate economic benefits and food aid for humanitarian benefits. However, food surplus' term is not commonly used to describe this positive meaning (Atkins and Bowler 2016; Huang et al. 2020). The term food surplus is always confused with food wastage because it has sustainable method for tackling the food wastage management, and it may be used as a safeguard against food scarcity. The food surplus is considered as global environmental issue which does not eliminate the food deficits, especially, in developing countries. This big debate among the food wastage literatures is based on two gaps; between food production and consumption and the total current food availability and need by 2050. Therefore, comparing the food supply per capita with food availability at the market level reveals that in some developed countries, US and some European Union (EU) countries, the food surplus exceeds 1,000 kilocalories (kcal) per capita (Papargyropoulou et al. 2014).

## 2.2 *Types of Food Waste*

According to FAO, food waste is all the edible food that is going to human consumption, but it gets wasted at retail and consumption stages which can be found at the end (downstream) of the FSC (Al-Khateeb et al. 2021; FAO 2011; Garcia-Garcia et al. 2015; Kibler et al. 2018). Also, throwing food, that is still eatable, considers intended waste depending on public's behaviours and believes. For examples, uncalculated amount of purchased food for restaurants usage leads to food waste; purchasing a large quantity of greens by retailers for promotions, preparing massive meals for hospitality and special occasions, the expired food which the people think that it is nonedible anymore and in groceries the food under low demand which is usually disposed of (Huang et al. 2020; Papargyropoulou et al. 2014). According to Food Use for Social Innovation by Optimising Waste Prevention Strategies (FUSIONS) and the UK Waste and Resources Action Programme (WRAP), a food waste is any food that is wasted at the end of the food supply chain, including non-edible parts like peels, bones, or eggshells. This widens the definitions of FUSIONS and WRAP, making them more comprehensive (Garcia-Garcia et al. 2015). Because of the discrepancy in the definitions and considerations, the food waste can be classified into two categories: avoidable and nonavoidable food waste. This classification might help to locate area of preventable waste and address food sustainable strategies for waste reductions (Papargyropoulou et al. 2014).

### 2.2.1 Avoidable Food Waste

Based on WRAP definition, the avoidable food waste is the edible food that is discarded because of beyond need, leftovers, not attracting the consumers, or inedible food due to putrefaction. All the food that majority of human consumes through their beliefs and customs such as traditional practices, religious values, and individual choices included into avoidable category (GOV.UK 2017; Papargyropoulou et al. 2014). Elegant supermarkets take care of the food representation and what should look like and irregular shape of the fruit and vegetables are getting wasted regardless to its nutritional values or remaining time to expiration (Science 2021). In the restaurants and food services industry, the avoidable wasted food can be generated at front-office (plate waste) and back-office (kitchen, packaging and storing) operations. For example, buffets, burn food, food and water spilled, overstocking and the way that has been used in preparing the meals (Martin-Rios et al. 2018).

### 2.2.2 Nonavoidable Waste

The parts of the food that are produced as inedible under normal conditions during food services such as cooking, packing, and storing, including fruit peelings and meat bones, eyes, hairs, and coffee grounds come under the umbrella of this category (Bernstad et al. 2013; GOV.UK 2017; Papargyropoulou et al. 2014). Nonvoidable wasted food can be generated at front-office such as plate waste with eggshells or veggie skins and food trimmings or at back-office like packaging and equipment defects, food scraps to name as few examples (Martin-Rios et al. 2018).

## 2.3 Food Loss

Food loss is the edible food that is spoiled (wasted) occurring at an early stage (upstream) of FSC depending on FAO definition (Al-Khateeb et al. 2021; FAO 2011; Garcia-Garcia et al. 2015). It is fortuity wastag during post-yield or transportation of agricultural processing, and it cannot be marketed because of pest invasions or improper storage ways (Huang et al. 2020). Food losses is strongly related to schemes that need investment in infrastructure (Papargyropoulou et al. 2014). FAO states that food waste and loss are considered only for products that come under human consumption, except parts of products that are inedible and suitable for animal feeding. Thus, the food is originally designed for human consumption, but unintentionally, it becomes unplanned inedible for human (FAO 2011; Papargyropoulou et al. 2014). Based on this discussion, food loss can be classified to two groups: unplanned and planned inedible loss and both of them relying on end-of-life destination of the food which is no longer involve in human food supply chain. There are environmental and marketing factors such as weather fluctuations, agricultural pest invasion, animal infectious disease, shortage of product in the market and increase

in prices that differentiate between them (Garcia-Garcia et al. 2015; Spang et al. 2019). The planned and unplanned loss can be useful in achieve the environmental sustainability if local authorities valorise the loss and deal with them in smart way like using bioconversion and anaerobic digestion (AD) methods to convert the loss and waste to many types of bioenergy and fuel particularly, in developing countries that have financial constraints which lead to overcome high-cost of energy in their industrial drying systems by using the waste of fresh feedstocks. Moreover, it can be used as compost for agricultural lands or sending the loss to barns for animal feeding (FAO 2011; Spang et al. 2019). Fats, oils, and lignocelluloses (lignin, cellulose and hemicellulose) of food waste and loss are renewable sources of valuable chemicals and biorefinery. Green chemistry is combined with the FLW valorisation concept to produce chemicals from plant and animal biomass using environment friendly industrial conversion processes. Renewable chemistry has enormous advantages in terms of environmental safety, population health and energy efficiency. These benefits include waste prevention, the presence of new environmental chemicals lead to a reduction in the use of synthetic and toxic reagents, biodegradable product designs and processes, the presence of renewable materials, the use of catalysis instead of stoichiometric and pollution prevention methods. There is a variety of feedstocks that may be used to produce biofuels, such as biodiesel, biokerosene and natural gas, depending on the kind of biofuel the individual wishes to produce. Bioethanol production in Brazil is second in the world, behind only the United States. There is no need for oil imports, the market is stable and ethanol fuel may be used in all vehicles. Traditional bioethanol and biodiesel, both of which are derived from plants, have several disadvantages that renewable biofuels do not. More than 30% of the world's energy demands will meet by renewable biofuels by 2050. By then, annual production of biomass-based biodiesel would have risen to 21,463 million litres. There are three factors that make them appropriate for such conversion: a high hydrogen to carbon ratio and a high carbon bond saturation, as well as low water solubility. Additional benefits include high octane ratings reducing emissions of sulphur oxides, nitrogen oxides and particulates. This characteristics greatly support to minimise the quantity of pollution in the air (Isah and Ozbay 2020).

### 2.3.1 Planned Food Loss

When loss occurs intentionally through upstream stage, it would be considered as planned loss (FAO 2011; Spang et al. 2019). It plans to be used for other purposes as food for animal or insects (black soldier fly larvae). A study wherein four food loss disposal techniques have been compared: two of them have been used in South Korean wet pig feed and a dry pig feed as animal feeding style and two techniques used in United Kingdom (UK), anaerobic digestion and composting. Results showed that techniques used for animal feeding have better results and low environmental and health impacts in comparison to other two (Salemdeeb et al. 2017). The planned loss food can be a way to reduce accumulation of non-biodegradable packaging and address the food quality and safety issues, it also helps to avoid food-borne

diseases and infection (Guillard et al. 2018; Science 2021). Globally, minimizing the environmental impacts and dependence on fossil fuel of food packaging with saving natural resources are goals to access the sustainability in food consumption. Using agro-food waste to generate biodegradable material is a promising innovation of waste-based food packaging and supporting green economy.

### 2.3.2 Unplanned Food Loss

It occurs unintentionally through upstream stage due to insufficient storage techniques and lack in cooling facilities as well as fridge truck defects or long-distance transportation. However, if we could shorten the chain of food processing, we could solve unplanned loss by encouraging urban farming (Science 2021; Spang et al. 2019). More than 50% of population live in urban cities and the food production and processing happen in rural farms. Rural farms are places to generate food for a huge population, and themselves they have easy access to fresh foods that is extremely limited in urban cities. Urban farming and growing food in modern cities reduce the dependency on long-distance food supplies and emissions that are produced during food transportation, processing and packaging (Science 2021). Thus, ensuring a healthy life of the people in urban areas who are benefiting from the fresh food. It is very important to have some arrangements for growing fresh food close to urban population so that long transportation and other associated issues are skipped.

### 2.3.3 Post-harvest Food Loss

Food loss can happen as post-harvest that reveals quantitative and qualitative loss at the production stage throughout handling, processing, storage and packaging phases (FAO 2011). Post-harvest loss is estimated around 2600 kilocalories (kcal) per capita per daily including animal feed and household waste (Papargyropoulou et al. 2014). In fact, when the raw products are harvested, there are many improper circumstances that impact the post-harvest and leads to increase the risk of losses such as, inadequate drying operations and storage efficiency, low quality materials of packaging, and inappropriate transportation facility. Furthermore, at the harvesting stage, processes and techniques that are machines or hand-picked can lead to losses. Furthermore, delaying in harvest causes exposing the grains to severe weather and pests which pushes a handsome amount of food to loss. The developing countries have the high levels of loss at post-harvest and at production stage, in contrast to developed countries, where it occurs at retails and consumption stage with an estimated quantity of > 20% of food loss. Mechanical harvesting is mostly used in developed countries for various commodities, while hand-picked is a common technique in developing countries, and it relies on labour's efforts that might take long time of harvesting causing more losses. The absence of investment in agricultural and Industrial drying systems leads to a major loss of food, compared to developed countries, that have greater features in food system and preparation including advanced automatic devices for

food production and irrigation with storage and packaging solutions. These differences between the developed and developing countries have been helpful insights on post-harvest losses (Spang et al. 2019).

### 3 Food Waste in Saudi Arabia Challenges and Solutions

The food waste in KSA is 427 kg/cap/y, taking the country to top food waster on global level even in comparison to industrialist countries in Europe and North America (Baig et al. 2019a, b). According to an estimate based on questionnaire from 1135 restaurant consumers, 1/3rd of the imported food goes into waste because of lower shelf life and warm climatic conditions of the country (Mirza Barjees Baig et al. 2022). Conclusions derived from a computer-based study on 2454 respondents indicates that public awareness, food security, food waste management, encouraging investors are re-visiting regulations are necessary steps to minimize the waste and convert it into useful products (Althumiri et al. 2021). There are several factors which affect the amount of wastage generated in the country including social and religious factors, strong legislation, financial support, active participation of stakeholders which need to be explored with exact scientific view point (Elshaer et al. 2021). A huge amount of food is wasted in order to make room for new groceries, the companies responsible for importing food are lacking awareness, inappropriate planning and excess of food is supplied during social gatherings. This food can be converted into compost and can add approximately 70 million USD to the economy of the country (Waqas et al. 2018). Countries in Africa and Saudi Arabia are understudied in terms of food waste, and a challenge of food safety and sovereignty might be faced any time, by these countries (Oelofse et al. 2020).

In 2012 the estimated potentials of power production from food waste was 990.40 MW/y from incineration and RDF (refuse derived fuel) scenario and it was predicted to reach 2196.76 MW by 2025 (Ouda et al. 2016). According to a study carried out in 2015, the country had a share of 50.6% (7.7 Mt/y, 0.7 kg/capita/day) food waste out of total municipal waste. It was estimated that the country can generate 2.99 TWh electricity through anaerobic digestion of the food waste (Nizami et al. 2015). A preliminary study regarding generation of biofuels reveals that Saudi Arab's and pilgrims population on the basis of 2017 data and by 2030 could produce 1.08–1.41 million tons of biodiesel and can add up to \$ 72.71 million to the country's economy. This huge aid to the economy is only possible to divert landfill towards technological processings. The process of biodiesel production can face a challenge of waste collection, segregation, impurities, reactor design and at the end, the quality of the produced biodiesel (Rehan et al. 2018).

A scientific landfill strategy for food waste management in KSA was proposed, efficient collection of methane can generate considerable revenue and save the consumption of conventional fossil fuels (Anjum et al. 2016). Laboratory studies of food waste samples were carried out where 99% methane and 1% other gases (NH<sub>3</sub>, CO, H<sub>2</sub>S and SO<sub>2</sub>) were detected at a temperature less than 50 °C. Under

these conditions a specific incubation period would be required for initiation of chemical degradation/gasification process, after 98 days maximum production of methane was observed. This study reveals that the environmental conditions of Saudi Arabia can positively support the process under normal condition and at even larger scale (Alruqaie and Alharbi 2012). Environmental sustainability in the country could be achieved only by installing bio-refineries as enshrined in country's vision 2030 (Mu'azu et al. 2019). Food waste can also be converted into  $H_2$  gas as well as biofertilizer through certain chemical processes which are clean and more environment friendly (Khan and Kaneesamkandi 2013; Miandad et al. 2017).

Besides, technological management of food waste, it is extremely important to spread awareness among dwellers to participate in the noble cause. A study carried out on 199 University level female students gave encouraging results, which points at this aspect of the issue (Al-Zahrani and Baig 2014; Alsawah et al. 2022). Several other parallel steps have to be taken such as establishment of food banks, effective cold storages and surplus food redistribution etc. which can help minimizing the waste.

#### 4 Adverse Environmental Effects of Food Loss/Waste

Food loss/waste has a negative impact on the environment such as it contributes to increase greenhouse gases and methane emissions which cause climate change, acidification, eutrophication of lakes, water and energy consumption, carcinogens to the soil, and land occupation. In this section, we will critically be discussed and compared various environmental potential impacts in the most common food waste treatment techniques such as landfills, incineration, anaerobic digestion, composting, animal feeding, and heat and moisture reactions.

Landfill is the conventional disposal method in the world, and it is 10 times more likely to contribute to climate change and human toxicity than acidification, eutrophication, and incineration (Gao et al. 2017; Lee et al. 2007). In US, Landfill produces a significant amount of methane gas with 25-fold more powerful effects on climate change than carbon dioxide  $CO_2$  (Hall et al. 2009). According to a research report, during the years of the reported period, only food surplus grew from 310 to 510 kcal/cap/day. This increase causes an increase of > 300% in emission of GHGs from 130 to 530 Mt  $CO_2$ eq/year. The total food requirement has been estimated to be between 2 and 20% by 2050 which can cause 1.9–2.5 Gt  $CO_2$ eq/year (Hiç et al. 2016). The amount of FW and loss during the period 1961–2011 grew by a factor of 3 (540 Mt to 1.6 Gt). The emission of GHGs accordingly increased from 680 Mt to 2.2 Gt  $CO_2$ eq (Porter et al. 2016). Most of the waste was generated in developing economies largely from fruit and vegetable items. In order to meet an increasing food demand, there is a run to establish a number of food factories and to industrialize the food sector, which compromises a long-term global inequality (Weis 2013).

The environmental impact of food wastage mainly come from upstream food supply chain processes and poor management. Large amounts of GHGs, global

warming potential (GWP) (Amicarelli et al. 2021), acidifying potential (AP), and eutrophication potential (EP) (Scherhauser et al. 2018), ozone depletion potential (ODP) (Mu et al. 2017), photochemical ozone formation (POF) (Fei et al. 2021), abiotic depletion potential (ADP) (Al-Rumaihi et al. 2020), energy use (EU), human toxicity potential (HTP), water use (WU) (Kibler et al. 2018), human health (HH) (Duret et al. 2019) and land use (LU) (Usubiaga et al. 2018) are commonly derived from food waste.

In Europe, emissions-related food waste assess at 15.7% GWP, 15.1% AP, and 15.2% EP, wherein meat products contributing the highest contribution to the overall food waste impact (Scherhauser et al. 2018). Food production and agriculture effect on natural resources, particularly water and energy, in US, the average energy required of food waste is around 300 million barrels of fuel per year and consumes 1/4 of the freshwater. The consumption of fresh water and energy during FW processing, directly impact global warming (Hall et al. 2009).

In Turkey, the footprints of carbon, water, and energy related food waste show that the energy-related food loss equals 8% of total national energy consumption per year; while the water disposal from only food loss estimated double the amount of the total national water consumed from all of the country sectors, and (GHG) has formed about 4% of national emissions generated from food wastage (Cakar et al. 2020).

Composting food waste has the greatest benefits to the environment than landfills or other disposal ways that apply for managing organic waste. Furthermore, composting is an alternative soil amendment that enhances the quality of the soil by reducing land-use change compared to peat (combusted plant matter extracted from wetland) (Saer et al. 2013).

In Qatar, windrow composting and anaerobic digestion (AD) combined composting, as the two common techniques for composting food waste, have been compared to estimate their negative impacts on the environment. Windrow composting has the greatest negative impact than anaerobic digestion combined composting in the GWP and acidification categories, while AD combined composting has the greatest impact on the human toxicity impact category (Al-Rumaihi et al. 2020).

Anaerobic digestion is another treatment method of recycling food waste. Comparing anaerobic digestion to landfilling, anaerobic digestion produces less adverse effects than landfilling on all environmental impact categories (Tonini et al. 2018). However, digestate fertilizer could be an interesting and better option than chemical fertilizer if some of the recommended and potential improvements in digestate are considered, such as minimizing emissions from anaerobic digestion by using green energy instead of fossil fuels and lowering the temperature and pH of the digestate to prevent microbial activity (Chiew et al. 2015).

Valorisation food waste to biofuel or bio-based chemicals is eco-friendly treatment. In Sweden, food waste can convert into biogas, succinic acid (SA), and corn to SA with maintain its low the environmental adverse impacts and could be considered an emerging bioeconomy (Brunklaus et al. 2018).

Animal feeding is preferable option among different choices of food waste treatment techniques for minimising food waste volume and providing environmental and health benefits. However, it is still unlawful in the EU countries to give food waste to animals owing to lack of public support and the high cost of reintroducing it (Salemdeeb et al. 2017).

In general, the negative environmental impacts of FW are still more and need serious attention to be minimized through certain techniques.

In contrast, FW prevention in different food service sectors has a positive impact on the environment. In Europe, 13 case studies have been assessed the environmental benefits and impacts categories particularly, climate change and biodiversity of FW prevention in five subsectors care, hotels, restaurants, business and education canteens in Switzerland and Germany. For each meal, it is equivalent to 238 g of CO<sub>2</sub>. Approximately 10% of the total avoidable FW and 9% is due to biodiversity-related effects. Climate and biodiversity impacts may be reduced by 58% and 37%, respectively, if FW reduction scenario is adopted. Over 70% of the FW's consequences on the environment and human health have been mitigated (Beretta and Hellweg 2019).

The environmental impact estimations are a useful tool for food stakeholders to compare and identify gaps and hotspots in food waste management.

## 5 Strategies to Curb Food Loss/Waste

Although a range of treatment techniques are applied across the globe for food waste management, such as recycling, landfilling, incineration etc., however, they have certain obstacle due to mishandling and mismanagement. Besides, continuously increased food production and agriculture is further worsening the situation. In context of this situation, new innovations along with existing food waste management technologies to address key challenges of food waste collection and proper disposal. Here, we will shed light on some of the strategies and recommendations to avoid food waste disaster.

### 5.1 Zero Hunger Hero Strategy

FAO (2017) provides nine tips and practices that are encouraging less food waste and better people awareness about food reduction strategies and targeting Zero Hunger Hero. These nine practices aim to achieve food sustainability as given in Fig. 2. The strategy forces individuals to eat small portions of food at home and start diet to preserve your health, leave nothing behind or create a new dish from your leftover foods. Judicious and calculated shopping of items and their arrangement in the fridge on the basis of first in, first out. Set up a compost bin for food waste and send it to the closer farm or garden to be used for farming. The highly recommended practice is to donate the surplus food to the people who cannot afford to buy (FAO 2017; Science



Fig. 2 Zero hunger hero tips and practices

2021). Practicing the steps outlined above are extremely helpful to save food. A social campaign will help in this regard to motivate individual at any level to adopt these steps. To achieve the SDG concerning food loss and waste, needs considerations and policy from various angles including at the retail level (Cakar 2022).

## 5.2 Sustainable Food Loss/Waste Management

There are several challenges preventing effective food waste management, for instance, a lack of consumer awareness, inflexible commercial policies at the store level, suppliers who do not care about promoting environmental initiatives and employees who do not get enough training on things like food rotation. It is imperative that sustainable management techniques be implemented in order to decrease food waste more efficiently (Filimonau and Gherbin 2017).

A wide range of approaches to generating sustainable food waste management will be addressed in this section.

Food waste and its consequences are best addressed by reducing FW at the source, since the vast majority of waste is created during food preparation and collection, regardless of how it is processed. There are suggested methods used in order to reach sustainable food loss/waste management (Dilkes-Hoffman et al. 2018; Gao et al. 2017). As examples, the composting under aerobic condition and in-sink food waste processors unit (FWP) that grind and shredder FW, are the preferable food waste reduction options at home since they have the least environmental impact at low cost (Lundie and Peters 2005). In US, FWP has been utilised as an alternative option to landfills since 1927 (Iacovidou et al. 2012).

Establishing a comprehensive management system is a successful management has been proposed for FWM. It is an integrating education, motivation, and command-control techniques including regulations and stakeholders to obtain appropriate policies. For instance, Taiwan is the ideal example of comprehensive waste management and as result of this system increases recycling activities of the country to about 2,100 tons of FW per day, with annual revenue of about TWD 2.7 billion. An integrated management system is deadly recommended for sustainable FW management particularly, in developing countries (Thi et al. 2015). Moreover, it requires scientists from many sectors to collaborate to develop ideal methods and concepts more environment friendly, with utilise the least energy and water used, the least waste produced, and low cost (Morone et al. 2019).

Adopting the food energy water nexus (FEW nexus) in the context of FWM is an example for integrated comprehensive sustainable management. FEW impacts management framework takes into account the impact of food waste as well as the subsequent management of food waste and post-disposal. It requires reducing the production of food waste and estimating the management of unavoidable food loss and waste. Also, it should be a wide range of ways and actors from both government and individual levels to work as a team. It's important to understand that food waste affects FEW in many ways by modelling the whole system, establishing feedback loops between food waste production and FEW consequences, and investigating connections between awareness and individual behaviour. These all data is needed to make a fair judgement of the process (Kibler et al. 2018).

Utilizing the network activity system such as Corporate Social Responsibility (CSR) is another type of management strategies to improve the transparency between organizations' activities and community and to integrate social and environmental fears in their commerce. Donation, institutionalization, and food waste reduction examples of CSR have been proven their efficiency in food controlling to achieve food security and contribute sustainable consumption and production (SDG 12). In addition, it leads to increase the quality of donated food, support fresh and healthy food for society and reach to a great number of needy people (SDG 2, 3 and 1). Furthermore, CSR can involve different organizations and companies in food waste recycling (SDG 16) (Moggi et al. 2018).

Also, enhancing public education to raise awareness and the knowledge among the population and engage the locals in the system that reduce food waste. For example, create new green alternative products that help to have a better value for the end-user with adopting a new distribution activity to embrace both the producers and

consumers in the food production and distribution network for well understanding of the social concerns (Al-Obadi et al. 2022).

Innovative management practices can help achieve sustainable management and reduce food waste. Incremental and radical innovation are some of the types of inventive practices that the food industry applies in its management. Incremental innovation is the gradual improvement of the system, integrating processes and activities related to waste minimization with the latest technology. For instance, the green restaurant includes a green diet and equipment to attain zero-waste restaurants, doggy bags practice that encourages the customers to take their dining leftovers, and online applications platforms for food donations and end-of-day sales (Martin-Rios et al. 2018). In addition, food preservation or frozen food is additional example for incremental practice. In Austria, Fresh food waste accounts for 9.3%, while frozen food waste accounts for 1.6%. Generally, the total of food waste derived from fresh foods is 5.8 times greater than that of frozen foods (Martindale and Schiebel 2017). While radical innovation requires a lot of fresh knowledge and expertise, and it will take a lot of time, money, and effort for people to come up with novel solutions to the issue of food waste. For example, the waste generated by paper and pulp mills is converted into power using this technology (Martin-Rios et al. 2018). Likewise, Smart Garbage System, SGS is an Internet of Things (IoT) as a part of this approach which would achieve the highest levels of for organic waste management besides to minimizing the economic and environmental adverse impacts of FW production and supporting the circular economy concept (Abdullah et al. 2022; Hong et al. 2014).

Prioritize food waste prevention based on the environmental waste hierarchy that can be used to achieve sustainable food waste management (Cristóbal et al. 2018). Prevention of food waste becomes the preferable choice, followed by redistribution to needy people since they have low environmental impact with high cost-effective than others, then to animal feeding then, Anaerobic digestion and composting are becoming more popular ways to deal with food waste followed by thermal treatments with energy recovery and land spreading where it is used with plant-based products for agricultural purposes. Incineration and landfilling are becoming at the last management option, and they must be avoided based on their environmental impact and lack of positive outcomes (Garcia-Garcia et al. 2015).

Categorization food waste is critical to discovering the best strategy to manage and dispose of FW in an environment friendly manner. Food waste can be classified into categories based on nine phases or criteria: edibility, state, origin, complexity, animal product, stage of the supply chain, treatment, packaging, packaging biodegradable. Efficient framework must be developed for each of these criteria. Consideration is given to the positive and negative impacts, as well as the environmental, economic, and social ramifications of each criteria (Garcia-Garcia et al. 2015, 2017).

Power consumption, process efficiency, disposal costs, and emissions all contribute to the cost of improving food waste management systems in a sustainable manner (Lee et al. 2007).

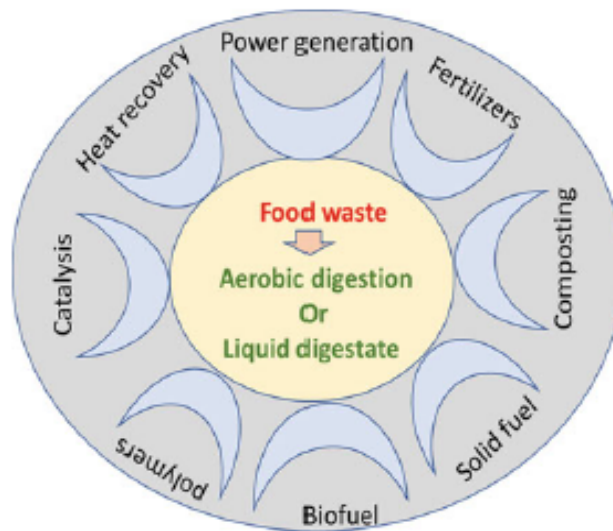
### 5.2.1 Value Added Products

Most strategies that have been used in food waste management focus on minimizing food waste rather than valorising the waste as a good and sustainable alternative solution. Value added products can be derived from food waste valorisation such as biofertilizers, biofuel, composting, polymers etc. (Fig. 3). Biofertilizers can be improved soil health, other value added products can also be used to retain water worth to be used in arid regions of the world to increase food production, and bioenergy can be utilised to reduce our dependence on fossil fuels (Morone et al. 2019). Fats, proteins, and bioethanol can be extracted from plant-based waste by using available technologies (Garcia-Garcia et al. 2015). Biofuel and bioproducts might decrease greenhouse gas emissions from landfills and preserve natural resources like coal and fossil fuels, therefore FW could offer environmental, social, and economic benefits (Giroto et al. 2015). High-tech strategies including thermal and biological waste treatment technologies are proposed for sustainable management since they are both cost-effective and environmentally benign. Thermal treatment, which contains hydrothermal carbonization, ethanol production and fermentation. Biological treatment that includes anaerobic digestion, mechanical–biological treatment and composting (Ananno et al. 2021).

Anaerobic digestion is type of sustainable management method for dealing with food waste since it is inexpensive, creates minimal waste, and transforms food waste into a sustainable source of power generation, solid fuel, and heat recovery (Fig. 3). It needs enzymatic hydrolysis, acid formation, and gas production (methanogenesis) with a set of microorganisms to produce bio-based products and maintain balance and stability of anaerobic digestion (Paritosh et al. 2017).

For example, Insect bioconversion can produce manure and dried larvae that is an interesting option in terms of covering the demand of feed production by using dried

**Fig. 3** Value added products obtained from food waste management



larvae in aquaculture feedings. For instance, biotransformation of Black Soldier Fly Larvae (BSFL) namely, *Hermetia illucens*, can produce 300 kg of dry larvae and 3346 kg of compost from 10 tons of discarded food. BSFL reduces organic waste weight by 50% in a faster time than conventional composting. Also, insect-based product is rich resource for biodiesel production and organic fertilizer which lead to decline in GHGs. Generally, the BSFL organic waste treatment system is a green technology and sustainable (Amrul et al. 2022; Salomone et al. 2017).

Damaged ecosystems and habitats may be repaired using microorganisms and the enzymes as part of a bioremediation technique. For example, pesticides, herbicides, insecticides, cleaning chemicals may convert them into less toxic substances to be absorbed into organisms and environment due to apply bioremediation techniques. Fruits and vegetables, olive oil, fermentation, dairy products, meat, and poultry are all ideal uses for bioremediation in the food industry. Bioremediation is an effective method for dealing with environmental pollution caused by waste from food industry (Thassitou and Arvanitoyannis 2001).

The FWM should be a comprehensive strategy that takes into consideration social constructionism, intellectual concerns, and organisational aims and policy plans in addition to management (Martin-Rios et al. 2018).

### 5.3 Legislations and Laws

Managing food waste is one of the wide world greatest challenges. The four R's: Reduce, Reuse, Recycle, and Recover is used as an indicator for waste hierarchy in reducing and managing food waste. To improve food waste reduction should integrate the multi-parties to cooperate in waste management strategies and implementations, involving governments' authorities, private industrial companies, households, and changing individual and culture waste disposal practices (Al Qahtani et al. 2021).

In Japan, the food recycling Law was enacted in 2001 according to this law, manufacturers and emitters are encouraged to turn food waste into compost or animal feed as well as biogas or heat from incineration. Competition from synthetic fertilisers, worries over safety and a low demand for recycled materials have made it difficult for recycled compost to gain attention. As a consequence, in 2007 the Law was revised to emphasise the significance of food recycling named (Loop Recycling) which permits recycling facilities to collect and transport food waste across municipal borders with requirements of purchasing farm products that use food waste-derived products, such as compost and animal feed to complete the loop (Takata et al. 2012).

Under the new law, more food waste is collected and recycled, with high environmentally beneficial and less expensive. Dry-feeding and bio-gasification procedures have lower GWPs because commercial feed and electricity have a significant influence on CO<sub>2</sub> emissions. It is possible for animal feed facilities to vary greatly in their usage of energy, food waste moisture contents and recycled materials while drying food (Takata et al. 2012).

In the USA, there are several legislations and strategies in different states for limiting landfills disposal of food waste, for example, California, Connecticut, Massachusetts, Vermont, Portland, San Francisco, Seattle, and New York. The laws emphasise source segregations and implement organic recycling programs for businesses, institutes, and residences which are food waste generators (Hodge et al. 2016).

In Korean government, has series of strict laws, for example, sorting food waste at source and implement volume-based charge system, generation gradually decreased from 1998. In 2005, landfills were banned which accounted for more than 90% of wasted food, and it replaced by recycling system (Lee et al. 2007).

Moreover, there are some countries such as Brazil, Turkey, Malaysia, Mexico, Costa Rica, Romania, South Africa, Belarus and Chin who have passed adequate laws with a timeline to achieve sustainable FW management. In Brazil, it aimed to end all open dumps by 2014 and to separate and collect 36% of recyclable waste and 53% of organic waste by 2030. In Turkey, the operation of composting and power generation facilities using methane gas is mandated by law to reduce the amount of landfill of FW (Thi et al. 2015).

Comprehensive FWM policies or programmes have not yet been put in place, in many countries throughout the globe. In KSA, food waste recycling has begun, however only a tiny fraction of the country's food waste is produced by informal activities. Saudi Arabia's Eastern Province has set up food waste recycling programme to encourage individuals to cook fewer meals, thereby reducing food waste. Laws are still lacking, landfilling is prevalent, public views are negative, and there is a lot of ambiguity especially public acceptability of FW's value-added products. Saudi Arabia's annual MSW and FW outputs might climb to 6.7 million tonnes by 2032 if no additional stringent FWM regulations or laws are implemented (Mu'azu et al. 2019).

In Bangladesh, there have not policy or law to shift municipal solid waste (MSW) management system. Organic waste is not yet separated from other waste or mixed with municipal rubbish. The MSW management still following the conventional formal system landfilling, is managed by municipalities. Besides, a community initiative that relies on the community to voluntarily dispose of its own waste, and an informal system that uses informal labour to dispose of waste (Ananno et al. 2021).

#### **5.4 Circular Bioeconomy Approach**

Circular economy and bioeconomy ideas are being incorporated into economic activities. According to Circular Economy Action Plan, circular economy is conservation the value of the products or raw material in the economy for a long period throughout utilizing waste hierarchy, which includes sharing, reusing, redistributing, and recycling to produce secondary products with decreased waste and CO<sub>2</sub> (European Commission 2015; Mak et al. 2020). The bioeconomy is the generation of renewable

biological resources with converting them into value-added products such as food, animal feeding, bio-based products and bioenergy.

Food waste conversion link bioeconomy with circular economy by ending up the food waste in organic waste recycling, energy, recovery or landfill disposal. Consequently, circular bioeconomy (CBE) could be the overlap of the concepts of a circular economy and bioeconomy, which aimed in improving resources to be efficient and environmentally friendly. They concepts are focussed on reducing greenhouse gases (GHGs) footprint and fossil carbon demands and valorising waste streams. Circular bioeconomy concept shares the same targets, which are enhancing the efficiency of resource utilization and valorisation waste materials, decreasing the gaseous emissions of during manufacturing and extraction processes (Mak et al. 2020). For example, food waste (eggshell and fly ash) can be utilized for industrial use to remove cadmium from wastewater. The materials used in the design are low cost, reusable, mass-usable, eco-friendly and have high performance (Segneanu et al. 2022).

A sustainable circular bioeconomy based on biomass may help tackle a variety of global environmental issues such as climate change, population expansion, limited natural resources and a rising need for food and materials. So far, the renewable energy directives didn't specify how biomass may be utilised to generate electricity or any other kind of power. It may be difficult to obtain energy back because of present constraints and economic decarbonization, which involves transitioning from fossil fuels to biomass (Mak et al. 2020).

The transition from the liner economy to the new concept circular bioeconomy concept to have closed loop of the FWM, and it requires the use of efficient technologies in a cost-effective and environmentally friendly design.

The Kingdom of Saudi Arabia (KSA) and the Gulf Countries (GCC) are following the linear economy concepts in their food waste management. For example, in Makkah city, the wasted food may increase to 1.60 million tons by 2030 due to the population growth, pilgrims to perform religious rituals, and practice the business-as-usual scenario (landfill site). If implement circular economy by bioprocessing recycling management (composting) in Makkah city, it would generate 0.23–0.40 million tons of compost with net revenue of 240–419 million Saudi Riyal (SAR), and a potential replacement of 124–216 kt of chemical fertilizers with savings will be 74–129 million SAR during 2015–2030. Also, implementing compost technology saving may be 618–1078 million SAR from the landfill and carbon related crediting, and reduce 0.043–0.076 million tons of Methane (CH<sub>4</sub>) emissions with net revenue of 1626 million SAR to the national economy of KSA in 2030. This proposed scenario would help the decision-makers establishing a suitable sustainable food waste management (Rashid and Shahzad 2021).

## 6 Steps to Be Taken for Sustainable FW Management

Here are some of recommendations which can help to manage FW in a judicious way:

To encourage research and innovations in the field of food waste management and cooperation with universities, research centres and institutions to evaluate the actual and potential quantities, expends and revenues of FW to make adequate decision for handling FWM and increase stakeholder's contributions in the field. Increase the public awareness and, in this case, it is important to use social media and television to educate individuals on how to plan and manage purchases. Food waste and loss control strategies, policies, and measures should be formed and prioritized to analyse the influence on the economic, nutritional and environmental cost along the food supply chain and water, energy and food security nexus and to be prepared for future unforeseen scenarios. Government in general should adopt a new approach such as reversal approach that focuses on sources reduction as first stage and land-filling as last stage in food waste treatment. Additionally, they should implement a policy for sorting and segregation FW at source for cost saving on collection, labour, transportation, and land value. Initiate and introduce fees and charges policy for FW generators to encourage food waste reduction practices and support different FWM services. Investors should utilize organic waste that estimates 40% of solid waste in Saudi Arabia to produce energy which helps to establish budget allocation for FWM and to meet circular economy concept. Encourage the mobilization of regional and global efforts through cooperative initiatives. For example, the collaboration among the GCC countries in this regard could help GCC countries to contribute corrective actions and measures to prevent FLW. The differentiation of the food wastage terminologies and classifications should be internationally unified to strengthen the food waste management and prevention in the globe.

## 7 Conclusion

Although food production is continually demand, its waste should adequately be managed to avoid the negative environmental and economic impacts. To achieve this goal, governmental and nongovernmental organization should adopt comprehensive sustainable approach, and they both must work together to ensure future sustainability and reduce the effects of the waste mismanagement. Also, it is essential to follow circular bioeconomy practice in food manufactories to support green economy and maintain the exist of natural resource for longer period. Moreover, they should establish a strong legislations and strategies along with raising public awareness for overcoming the burden gap in food waste management.

**Acknowledgements** There are no potential financial or other sources to be acknowledged.

**Conflict of Interest** Authors have reviewed and approved the manuscript and have nothing to be declared in terms of conflict of interest.

## References

- Abdullah N, Al-Wesabi OA, Mohammed BA, Al-Mekhlafi ZG, Alazmi M, Alsaffar M, Anbar M, Sumari P (2022) Integrated approach to achieve a sustainable organic waste management system in Saudi Arabia. *Foods* 11(9):1214
- Al-Khateeb SA, Hussain A, Lange S, Almutari MM, Schneider F (2021) Battling food losses and waste in Saudi Arabia: mobilizing regional efforts and blending indigenous knowledge to address global food security challenges. *Sustainability* 13(15):8402
- Al-Obadi M, Ayad H, Pokharel S, Ayari MA (2022) Perspectives on food waste management: prevention and social innovations. *Sustainable Production and Consumption*
- Al-Rumaihi A, McKay G, Mackey HR, Al-Ansari T (2020) Environmental impact assessment of food waste management using two composting techniques. *Sustainability* 12(4):1595
- Al-Zahrani K, Baig M (2014) Food waste in the Kingdom of Saudi Arabia: need for extension education programs to increase public awareness. Paper presented at the proceedings of international academic conferences
- Al Qahtani S, Al Wuhayb F, Manaa H, Younis A, Sehar S (2021) Environmental impact assessment of plastic waste during the outbreak of COVID-19 and integrated strategies for its control and mitigation. *Reviews on Environmental Health* 37:585–596
- Alruqaie IM, Alharbi BH (2012) Environmental advantage assessment of recycling food waste in Riyadh, Saudi Arabia. *Res J Environ Sci* 6(6):230
- Alsawah G, Saleh W, Malibari A, Lashin MM, AlGhamdi T (2022) Food waste, attitudes and preferences of young females: a case study in Saudi Arabia. *Sustainability* 14(4):1961
- Althumiri NA, Basyouni MH, Duhaim AF, AlMousa N, AlJuwaysim MF, BinDhim NF (2021) Understanding food waste, food insecurity, and the gap between the two: a nationwide cross-sectional study in Saudi Arabia. *Foods* 10(3):681
- Amicarelli V, Lagioia G, Bux C (2021) Global warming potential of food waste through the life cycle assessment: an analytical review. *Environ Impact Assess Rev* 91:106677. <https://doi.org/10.1016/j.eiar.2021.106677>
- Amrul NF, Kabir Ahmad I, Ahmad Basri NE, Suja F, Abdul Jalil NA, Azman NA (2022) A review of organic waste treatment using black soldier fly (*Hermetia illucens*). *Sustainability* 14(8):4565
- Ananno AA, Masud MH, Chowdhury SA, Dabnichki P, Ahmed N, Arefin AME (2021) Sustainable food waste management model for Bangladesh. *Sustainable Production and Consumption* 27:35–51
- Anjum M, Miandad R, Waqas M, Ahmad I, Alafif Z, Aburizaiza A, Akhtar T (2016) Solid waste management in Saudi Arabia. *Applied Agriculture and Biotechnology* 1:13–26
- Atkins P, Bowler I (2016) *Food in society: economy, culture, geography*. Routledge, London
- Baig MB, Al-Zahrani KH, Schneider F, Straquadine GS, Mourad M (2019a) Food waste posing a serious threat to sustainability in the Kingdom of Saudi Arabia—a systematic review. *Saudi Journal of Biological Sciences* 26(7):1743–1752
- Baig Mbaz, Khodran H, Schneider F, Straquadine Gary S, Mourad M (2019b) Food waste posing a serious threat to sustainability in the Kingdom of Saudi Arabia—a systematic review. *Saudi Journal of Biological Sciences* 26(7):1743–1752. <https://doi.org/10.1016/j.sjbs.2018.06.004>
- Baig MB, Alotaibi BA, Alzahrani K, Pearson D, Alshammari GM, Shah AA (2022) Food waste in Saudi Arabia: causes, consequences, and combating measures. *Sustainability* 14(16):10362
- Bashraheel A (2020) Saudi Arabia seeks to vitalize waste management sector, Arab News. Retrieved from <https://arab.news/ngwfk>

- Beretta C, Hellweg S (2019) Potential environmental benefits from food waste prevention in the food service sector. *Resour Conserv Recycl* 147:169–178
- Bernstad Saraiva Schott A, Vukicevic S, Bohn I, Andersson T (2013) Potentials for food waste minimization and effects on potential biogas production through anaerobic digestion. *Waste Manage Res* 31(8):811–819
- Brunklaus B, Rex E, Carlsson E, Berlin J (2018) The future of Swedish food waste: an environmental assessment of existing and prospective valorization techniques. *J Clean Prod* 202:1–10
- Cakar B (2022) Bounce back of almost wasted food: Redistribution of fresh fruit and vegetables surpluses from Istanbul's supermarkets. *J Clean Prod* 362:132325. <https://doi.org/10.1016/j.jclepro.2022.132325>
- Cakar B, Aydin S, Varank G, Ozcan HK (2020) Assessment of environmental impact of FOOD waste in Turkey. *J Clean Prod* 244:118846
- Chiew YL, Spångberg J, Baky A, Hansson PA, Jönsson H (2015) Environmental impact of recycling digested food waste as a fertilizer in agriculture—a case study. *Resour Conserv Recycl* 95:1–14
- Corrado S, Caldeira C, Eriksson M, Hanssen OJ, Hauser HE, van Holsteijn F, Liu G, Östergren K, Parry A, Secondi L (2019) Food waste accounting methodologies: challenges, opportunities, and further advancements. *Glob Food Sec* 20:93–100
- Cristóbal J, Castellani V, Manfredi S, Sala S (2018) Prioritizing and optimizing sustainable measures for food waste prevention and management. *Waste Manage* 72:3–16
- Dilkes-Hoffman LS, Lane JL, Grant T, Pratt S, Lant PA, Laycock B (2018) Environmental impact of biodegradable food packaging when considering food waste. *J Clean Prod* 180:325–334
- Duret S, Hoang HM, Derens-Bertheau E, Delahaye A, Laguerre O, Guillier L (2019) Combining quantitative risk assessment of human health, food waste, and energy consumption: the next step in the development of the food cold chain? *Risk Anal* 39(4):906–925. <https://doi.org/10.1111/risa.13199>
- Elshaer I, Sobaih AEE, Alyahya M, Abu Elnasr A (2021) The impact of religiosity and food consumption culture on food waste intention in Saudi Arabia. *Sustainability* 13(11):6473
- European Commission (2015) Communication from the commission to the European parliament, the council, the European economic and social committee and the committee of the regions. Closing the loop—an EU action plan for the circular economy. European Commission Retrieved from <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52015DC0614>
- FAO (2011) Global food losses and food waste—extent, causes and prevention. Food and Agriculture Organization of the United Nations, Rome
- FAO (2014) SAVE FOOD: global initiative on food loss and waste reduction: definitional framework of food loss. Food and Agriculture Organization of the United Nations, Rome
- FAO (2017) 9 tips for reducing food waste and becoming a #ZeroHunger hero. Retrieved 26 Jan 2022. <https://www.fao.org/zhc/detail-events/en/c/889172/>
- Fei X, Jia W, Chen T, Ling Y (2021) Life-cycle assessment of two food waste disposal processes based on anaerobic digestion in China. *J Clean Prod* 293:126113. <https://doi.org/10.1016/j.jclepro.2021.126113>
- Filimonau V, Gherbin A (2017) An exploratory study of food waste management practices in the UK grocery retail sector. *J Clean Prod* 167:1184–1194
- Gao A, Tian Z, Wang Z, Wennersten R, Sun Q (2017) Comparison between the technologies for food waste treatment. *Energy Procedia* 105:3915–3921
- Garcia-Garcia G, Woolley E, Rahimifard S (2015) A framework for a more efficient approach to food waste management. *Int J Food Eng* 1(1):65–72
- Garcia-Garcia G, Woolley E, Rahimifard S, Colwill J, White R, Needham L (2017) A methodology for sustainable management of food waste. *Waste Biomass Valor* 8(6):2209–2227
- Giroto F, Alibardi L, Cossu R (2015) Food waste generation and industrial uses: a review. *Waste Manage* 45:32–41
- GOV.UK. (2017) Food waste: a response to the policy challenge, UK. Retrieved from [www.gov.uk/go-science](http://www.gov.uk/go-science)

- Grizzetti B, Pretato U, Lassaletta L, Billen G, Garnier J (2013) The contribution of food waste to global and European nitrogen pollution. *Environ Sci Policy* 33:186–195. <https://doi.org/10.1016/j.envsci.2013.05.013>
- Guillard V, Gaucel S, Fornaciari C, Angellier-Coussy H, Buche P, Gontard N (2018) The next generation of sustainable food packaging to preserve our environment in a circular economy context. *Front Nutr* 5:121
- Hall KD, Guo J, Dore M, Chow CC (2009) The progressive increase of food waste in America and its environmental impact. *PLoS ONE* 4(11):e7940
- Hiç C, Pradhan P, Rybski D, Kropp JP (2016) Food surplus and its climate burdens. *Environ Sci Technol* 50(8):4269–4277. <https://doi.org/10.1021/acs.est.5b05088>
- Hodge KL, Levis JW, DeCarolis JF, Barlaz MA (2016) Systematic evaluation of industrial, commercial, and institutional food waste management strategies in the United States. *Environ Sci Technol* 50(16):8444–8452
- Hong I, Park S, Lee B, Lee J, Jeong D, Park S (2014) IoT-based smart garbage system for efficient food waste management. *The Scientific World Journal*
- Huang CH, Liu SM, Hsu NY (2020) Understanding global food surplus and food waste to tackle economic and environmental sustainability. *Sustainability* 12(7):2892
- Iacovidou E, Ohandja DG, Gronow J, Voulvoulis N (2012) The household use of food waste disposal units as a waste management option: a review. *Crit Rev Environ Sci Technol* 42(14):1485–1508
- Isah S, Ozbay G (2020) Valorization of food loss and wastes: feedstocks for biofuels and valuable chemicals. *Front Sustain Food Syst* 4:82
- Khan MSM, Kanesamkandi Z (2013) Biodegradable waste to biogas: renewable energy option for the Kingdom of Saudi Arabia. *Int J Innov Appl Stud* 4(1):101–113
- Kibler KM, Reinhart D, Hawkins C, Motlagh AM, Wright J (2018) Food waste and the food-energy-water nexus: a review of food waste management alternatives. *Waste Manage* 74:52–62
- Lee SH, Choi KI, Osako M, Dong JI (2007) Evaluation of environmental burdens caused by changes of food waste management systems in Seoul, Korea. *Sci Total Environ* 387(1–3):42–53
- Lundie S, Peters GM (2005) Life cycle assessment of food waste management options. *J Clean Prod* 13(3):275–286
- Mak TM, Xiong X, Tsang DC, Iris K, Poon CS (2020) Sustainable food waste management towards circular bioeconomy: policy review, limitations and opportunities. *Biores Technol* 297:122497
- Martin-Rios C, Demen-Meier C, Gössling S, Cornuz C (2018) Food waste management innovations in the foodservice industry. *Waste Manage* 79:196–206
- Martindale W, Schiebel W (2017) The impact of food preservation on food waste. *British Food Journal* 119:2510–2518
- Miandad R, Rehan M, Ouda OKM, Khan MZ, Shahzad K, Ismail IMI, Nizami AS (2017) Waste-to-hydrogen energy in Saudi Arabia: challenges and perspectives. In: Singh A, Rathore D (eds) *Biohydrogen production: sustainability of current technology and future perspective*. Springer India, New Delhi, pp 237–252
- Moggi S, Bonomi S, Ricciardi F (2018) Against food waste: CSR for the social and environmental impact through a network-based organizational model. *Sustainability* 10(10):3515
- Morone P, Koutinas A, Gathergood N, Arshadi M, Matharu A (2019) Food waste: challenges and opportunities for enhancing the emerging bio-economy. *J Clean Prod* 221:10–16
- Mu D, Horowitz N, Casey M, Jones K (2017) Environmental and economic analysis of an in-vessel food waste composting system at Kean University in the U.S. *Waste Manage* 59:476–486. <https://doi.org/10.1016/j.wasman.2016.10.026>
- Mu'azu ND, Blaisi NI, Naji AA, Abdel-Magid IM, AlQahtany A (2019) Food waste management current practices and sustainable future approaches: a Saudi Arabian perspectives. *J Mater Cycles Waste Manag* 21(3):678–690
- Närviäinen E, Mesiranta N, Mattila M, Heikkinen A (2019) Food waste management: solving the wicked problem. Springer Nature, Cham
- Nizami AS, Rehan M, Ouda OK, Shahzad K, Sadeq Y, Iqbal T, Ismail IM (2015) An argument for developing waste-to-energy technologies in Saudi Arabia. *Chem Eng Trans* 45:337–342

- Oelofse S, Nahman A, Baig MB, Saleemdeen R, Nizami AS, Reynolds C (2020) Food waste within South Africa and Saudi Arabia. In: Reynolds C, Soma T, Spring C, Lazell J (eds) Routledge handbook of food waste, 1st edn. Routledge, New York, pp 207–224
- Ouda OKM, Raza SA, Nizami AS, Rehan M, Al-Waked R, Korres NE (2016) Waste to energy potential: a case study of Saudi Arabia. *Renew Sustain Energy Rev* 61:328–340. <https://doi.org/10.1016/j.rser.2016.04.005>
- Papargyropoulou E, Lozano R, Steinberger JK, Wright N, bin Ujang Z (2014) The food waste hierarchy as a framework for the management of food surplus and food waste. *J Clean Prod* 76:106–115
- Paritosh K, Kushwaha SK, Yadav M, Pareek N, Chawade A, Vivekanand V (2017) Food waste to energy: an overview of sustainable approaches for food waste management and nutrient recycling. *BioMed Research International*
- Porter SD, Reay DS, Higgins P, Bomberg E (2016) A half-century of production-phase greenhouse gas emissions from food loss and waste in the global food supply chain. *Sci Total Environ* 571:721–729. <https://doi.org/10.1016/j.scitotenv.2016.07.041>
- Rashid MI, Shahzad K (2021) Food waste recycling for compost production and its economic and environmental assessment as circular economy indicators of solid waste management. *J Clean Prod* 317:128467
- Rehan M, Gardy J, Demirbas A, Rashid U, Budzianowski WM, Pant D, Nizami AS (2018) Waste to biodiesel: a preliminary assessment for Saudi Arabia. *Biores Technol* 250:17–25. <https://doi.org/10.1016/j.biortech.2017.11.024>
- Saer A, Lansing S, Davitt NH, Graves RE (2013) Life cycle assessment of a food waste composting system: environmental impact hotspots. *J Clean Prod* 52:234–244
- Saleemdeen R, Zu Ermgassen EK, Kim MH, Balmford A, Al-Tabbaa A (2017) Environmental and health impacts of using food waste as animal feed: a comparative analysis of food waste management options. *J Clean Prod* 140:871–880
- Salomone R, Saija G, Mondello G, Giannetto A, Fasulo S, Savastano D (2017) Environmental impact of food waste bioconversion by insects: application of life cycle assessment to process using *Hermetia illucens*. *J Clean Prod* 140:890–905
- Scherhauser S, Moates G, Hartikainen H, Waldron K, Obersteiner G (2018) Environmental impacts of food waste in Europe. *Waste Manage* 77:98–113. <https://doi.org/10.1016/j.wasman.2018.04.038>
- Science C (2021) Food and climate: the impact of food on the environment. Retrieved 26 Jan 2022. <https://climatescience.org>
- Segneanu AE, Marin CN, Vlase G, Cepan C, Mihailescu M, Muntean C, Grozescu I (2022) Highly efficient engineered waste eggshell-fly ash for cadmium removal from aqueous solution. *Sci Rep* 12(1):1–31
- Spang ES, Moreno LC, Pace SA, Achmon Y, Donis-Gonzalez I, Gosliner WA, Jablonski-Sheffield MP, Momin MA, Quested TE, Winans KS, Tomich TP (2019) Food loss and waste: measurement, drivers, and solutions. *Annu Rev Environ Resour* 44:117–156
- Takata M, Fukushima K, Kino-Kimata N, Nagao N, Niwa C, Toda T (2012) The effects of recycling loops in food waste management in Japan: based on the environmental and economic evaluation of food recycling. *Sci Total Environ* 432:309–317
- Teigiserova DA, Hamelin L, Thomsen M (2020) Towards transparent valorization of food surplus, waste and loss: clarifying definitions, food waste hierarchy, and role in the circular economy. *Sci Total Environ* 706:136033
- Thassitou P, Arvanitoyannis I (2001) Bioremediation: a novel approach to food waste management. *Trends Food Sci Technol* 12(5–6):185–196
- Thi NBD, Kumar G, Lin CY (2015) An overview of food waste management in developing countries: current status and future perspective. *J Environ Manage* 157:220–229
- Tonini D, Albizzati PF, Astrup TF (2018) Environmental impacts of food waste: learnings and challenges from a case study on UK. *Waste Manage* 76:744–766

- Usubiaga A, Butnar I, Schepelmann P (2018) Wasting food, wasting resources: potential environmental savings through food waste reductions. *J Ind Ecol* 22(3):574–584. <https://doi.org/10.1111/jiec.12695>
- Waqas M, Nizami AS, Aburizaiza AS, Barakat MA, Rashid MI, Ismail IMI (2018) Optimizing the process of food waste compost and valorizing its applications: a case study of Saudi Arabia. *J Clean Prod* 176:426–438. <https://doi.org/10.1016/j.jclepro.2017.12.165>
- Weis T (2013) The meat of the global food crisis. *The Journal of Peasant Studies* 40(1):65–85. <https://doi.org/10.1080/03066150.2012.752357>
- Xue L, Liu G, Parfitt J, Liu X, Van Herpen E, Stenmarck Å, O'Connor C, Östergren K, Cheng S (2017) Missing food, missing data? A critical review of global food losses and food waste data. *Environ Sci Technol* 51(12):6618–6633. <https://doi.org/10.1021/acs.est.7b00401>

## المخلص

تسعى هذه الدراسة إلى التحقيق في التوافر المستدام لإدارة المخلفات الغذائية (FWM) في المملكة العربية السعودية ، وتسليط الضوء على دورها في تحقيق أهداف التنمية المستدامة. ينصب التركيز الأساسي على دراسة ممارسات إدارة النفايات الغذائية الحالية داخل مدينة الخبر ، المملكة العربية السعودية ، مع توضيح العوامل والتحديات والقيود المحتملة التي تؤثر عليها. تحدد الدراسة خمسة أهداف محددة تهدف إلى تعزيز الكفاءة وتعزيز الاستدامة ضمن إطار إدارة المخلفات الغذائية في المملكة العربية السعودية.

تتضمن الأهداف تقدير الوعي والمعرفة العام والسلوكيات المتعلقة بإدارة المخلفات الغذائية ، بالإضافة إلى تحليل أدوار وتفاعلات ووجهات نظر أصحاب المصلحة في المملكة العربية السعودية. و تعزيز التوجيه وتقديم التوصيات التي يمكن أن تسهم في الحد من توليد مخلفات غذائية وآثارها البيئية من خلال استخدام خيارات إدارية مبتكرة. ومن خلال التنفيذ المنهجي لهذه الأهداف ، يسعى البحث إلى تحليل شامل لممارسات إدارة المخلفات الغذائية في مدينة الخبر ، المملكة العربية السعودية ، بهدف تحديد المحددات الحاسمة والتحديات والسبل المحتملة لتعزيز الكفاءة والاستدامة في نطاق مبادرات إدارة المخلفات الغذائية.

ينقسم البحث إلى خمسة فصول. الفصل الأول ، يعتبر الفصل التمهيدي والأساس للتحقيق البحثي الذي يلخص العناصر الرئيسية بما في ذلك أسئلة البحث ، والمشكلات المحددة ، والغرض من الدراسة وأهميتها ، ومخطط لهيكل البحث. أما الفصل الثاني يتعمق في مراجعة مكثفة للدراسات السابقة المتعلقة بدinاميكيات إنتاج المخلفات الغذائية ، والتداعيات البيئية ، والآثار الاجتماعية والاقتصادية. بالإضافة إلى ذلك ، فإنه يدرس ممارسات إدارة المخلفات الغذائية داخل المملكة العربية السعودية ، جنباً إلى جنب مع بدائل الإدارة المستدامة العالمية ، والاستراتيجيات ، والأدوات المنهجية الحالية التي تهدف إلى تعزيز الإدارة المستدامة للمخلفات الغذائية.

ويقدم الفصل الثالث الإجراءات المنهجية اللازمة لتحقيق أهداف وغايات الدراسة. ويشمل مناهج ومراحل منهجية متنوعة ، إلى جانب الأدوات المستخدمة لتحليل البيانات. تم إجراء الاستبيانات والملاحظات الميدانية والمقابلات مع أصحاب المصلحة من الأوساط الأكاديمية وقطاع التجزئة والمسؤولين الحكوميين والمستهلكين. ويعرض الفصل الرابع النتائج والمناقشات المستخلصة من الفصل الثالث السابق. يصف فيه تقييم الوعي العام من خلال التحليل الإحصائي. ويوفر إطار عمل مخطط لاتخاذ القرار المناسب في إدارة المخلفات الغذائية (FWMMDT) لتصنيف سبعة أنواع من المخلفات الغذائية السائدة في صناعة البيع بالتجزئة وربطها بخيارات إدارة المخلفات الغذائية المستدامة المختلفة. علاوة على ذلك ، يشرح الفصل تطوير عمليات المحاكاة والسيناريوهات القائمة على مجموعة شاملة من المتغيرات والعوامل ، مع دمج رؤى من أصحاب المصلحة المحليين. ويعمل هذا النهج على تيسير التخطيط الاستراتيجي وصنع القرار من خلال تمكين الجهات الفاعلة المحلية من التعبير عن وجهات نظرها مع تمكين واضعي السياسات من تعزيز فهم الضرورات المحلية، وبالتالي الحد من الصراعات وزيادة فعالية التدخلات النهائية في مجال السياسات. وأخيراً، يلخص الفصل الختامي من الدراسة مساهماتها، ويصف حدودها، ويقدم توصيات ذات صلة، ويقترح سبلاً لمساعدى إعادة البحث في المستقبل.

باختصار، تخلص الدراسة إلى أن المملكة العربية السعودية واجهت تحديات في تحقيق إدارة المخلفات الغذائية مستدام في الآونة الأخيرة، ويعزى ذلك في المقام الأول إلى عدم كفاية أصحاب المصلحة المحليين في توجيه ممارسات إدارة المخلفات الغذائية والإشراف عليها بطريقة مستدامة. ومع ذلك، فإن تنفيذ سياسات واستراتيجيات حكومية شاملة تتعلق إدارة المخلفات الغذائية عندما تكون واضحة ومستنيرة تماما، يمثل خيارا صالحا لتحقيق الاستدامة في هذا المجال.

جامعة البحرين

برنامج  
البيئة والتنمية المستدامة



كلية العلوم

## دور إدارة المخلفات الغذائية الحضرية في تحقيق التنمية المستدامة

أطروحة مقدمة كجزء من متطلبات الحصول على درجة الدكتوراه في البيئة والتنمية المستدامة

مقدمة من

شاهرة سعد سعيد القحطاني

الرقم الجامعي: ٢٠٢٠١٢٤٦٥

إشراف

د. أحمد عبد الفتاح

(استاذ مشارك)

جامعة البحرين

مملكة البحرين

مايو ٢٠٢٤