Abstract

Reducing the food waste is the greatest challenge in the present times for sustainable food management systems that has significant economic, environmental and social impact on the food supply chain. The Circular Economy (CE) paradigm advocates the concept of the closed-loop economy endorsing more responsible utilization and appropriate exploitation of resources in contrast to the open-ended linear economic system of take-make-use and dispose. This chapter has explored agri food waste in the context of CE, triple bottom line (TBL) and sustainability. An alignment of circular strategies with the food waste hierarchy is proposed that indicates practical application of the gradations of circularity in the food waste management that could lead to the development of sustainable food management system targeting the sustainable development goals of Zero Hunger and Responsible consumption and production. This chapter also highlights some opportunities and challenges of agri food waste in the application of circular bio-economy.

Key Words

Food Waste (FW), Circular Economy (CE), Tripple Bottom Line (TBL), Sustainability, Sustainable Development Goals (SDGs), Circular strategies, Food Supply Chain (FSC)

1. Introduction

Food waste reduction is one of the biggest sustainability challenges faced in the present times. According to an estimate of The UN Food and Agriculture Organisation (FAO) approximately 1.3 billion tonnes of food is wasted each year, amounting to one-third of all food produced globally for human consumption (1). Two common terms "food loss" and "food waste" are commonly used to represent the waste generated at different stages in the food supply chain (2). World Resources Institute defined Food Loss (FL) and Food Waste (FW) as "the unintended result of an agricultural process or technical limitation in storage, infrastructure, packaging, or marketing" and as "food that is of good quality and fit for human consumption but that does not get consumed because it is discarded" respectively. (3). According to European Union (EU) definition, FW is a "fractions of food and inedible parts of food removed from the food supply chain to be recovered or disposed" (4).

According to FAO (2021) food loss refers to the decrease in the quantity and quality of food lost at different stages of growing (pre-harvest), post-harvest and processing stages but not included the retail level whereas food waste is associated with the decrease in the quantity or quality of food that is fit for human consumption but is discarded due to decisions and actions of retailers, food service providers and consumers.

In addition to food waste and food loss a third term Food surplus (FS) is also described in the literature that represents the leftover edible food fit for human consumption. FS is generated at the retail and consumption stages of in the food supply chain (FSC) (5), but also refers to overproduction at the agricultural/primary production stage (6). Some of the surplus food changes into food waste due to ineffective management of food surplus (6) that need to be managed at different stages of food supply chain either by recovering for human consumption or preventing at source to limit the unnecessary use of natural resources (5).

A common expression of Food Loss and Waste (FLW) is also introduced in literature that combines the concept of food loss and food waste and represents the total share of food produced, retailed or served for human consumption but is not consumed and redirected to feed people, animals or used for new edible products (5).

All these definitions are considering the decrease in the quantity and quality of food at different stages of food production that starts from the pre harvesting till the food is available for consumption.

From last few years, the rate of food production has grown faster than the human population growth rate which resulted into food surplus that get lost or wasted. According to FAO, (2014) one third of the food is lost or wasted while flowing through the food supply chain (FSC). This has significant impact on the triple bottom line (economic, environmental and social) of the supply chain for many institutions (public and private sector). Food Waste (FW) also contributes to supply chain risks and food insecurity as well as greenhouse gases which arising from their decomposition if landfilled. Now, there is an urgency to stop this significant depletion of critical assets in food losses and waste at all tiers of supply chain (from manufacturer to end consumer).

The Circular Economy (CE) paradigm advocates the concept of the closed-loop economy endorsing more responsible utilization and appropriate exploitation of resources in contrast to the open-ended linear economic system of take-make-use and dispose. CE aims to recover the enviromental damage and improve the well beings of human that is highlighted by the practitioners (7) and academics. The most dominant aspect of CE is effective waste management practices where some of the practices could be more effective in certain sectors/conditions but fail in other sectors/situations.

One of such system of circular strategies is expressed in the form of gradations of circularity (shown in figure below). Gradations of circularity represents circular strategies (10Rs) in hierarchical order consist of refusing, rethinking, reducing, reusing, repairing, refurbishing, remanufacturing, repurposing, recycling, and recovering (8). The current study has proposed an alignment of these circular startegies with the food waste management hierarchy framework identified in literature (these are discussed in detail in section 4 and 5).

The chapter has explored the concept of CE, TBL, Sustainability, Food waste Hierarchies and proposed the alignment of CE practices with the food waste management hierarchy. The last section describes some challenges and opportunities for agri-food based CE.

2. The origin/emergence of Circular Economy (CE)

Circular Economy (CE) advocates the concept of the closed-loop economy in contrast to the open-ended linear economic system of take-make-use and dispose (7). The term Circular Economy was coined first time by Pearce and Turner in relation to the inter-linkages between the environmental and economic activities. Pearce and Turner derived inspiration for Circular Economy from the work of Boulding which described the earth as the closed and circular system having limited natural resources for the human activities emphasising the need for the existence of an equilibrium between the economy and environment. Circular Economy has emerged from a variety of concepts proposed by different authors in the past and recent times and developed the broad spectrum of postulates and principles of Circular Economy. The concept of Circular Economy was initially introduced during the 1970s by the Swiss architect and economist Walter Stahel who proposed that materials can be processed in a ‘closed loop’ that transforms ‘waste’ into a resource (9). Stahel (9) focused on the industrial ecology and proposed the industrial strategies of waste prevention, resource efficiency, regional job creation and dematerialisation of the industrial economy to conceptualise the loop economy. Stahel (9), proposed the sustainable business model for the loop economy (termed as spiral loop system) by; defining this loop system as a ‘Cradle-to-Cradle’ system and the linear model as Cradle-to-Grave, proposing the need for product life extension through reuse, repair, reconditioning and recycling and introducing the idea of selling utilisation instead of the ownership of goods allowing industries to earn profit without externalising the risk and cost of waste (10). All these concepts are now considered integral to the Circular Economy. Some other most relevant theoretical developments in this dimension are regenerative design (11), industrial ecology (12,13), Cradle to Cradle (14) and looped and performance economy (9).

The work of Ellen MacArthur Foundation is very important in the context of Circular Economy as it has a range of publications on the topic including a series of reports and a book by Webster. The Ellen MacArthur Foundation is also serving as a hub for business, academia and policymakers. Now the consultancies such as McKinsey & Co are working in collaboration with the Ellen MacArthur to tap into opportunities of CE.

The concept of CE evolved gradually and can be divided into three distinct stages. The first stage is the linear economy stage that initiated with the industrial revolution, technological development, overexploitation of resources and economic growth. However, in 60’s the concerns were raised at this developmental stage as a result of increasing interest on the environment by the ecologists such as Carson and the economists such as Boulding who suggested that earth is a closed and circular system with limited natural resources for human activities. Both ecologists and economists emphasised the need to recirculate the natural resources for developing an equilibrium between the economy and environment.

The second stage started with the increasing awareness of researchers and policymakers towards environmental protection. It led to the emergence of the concepts of loop economy (9) and the industrial metabolism[1] that led to the development of the strategies for the resource efficiency and waste prevention by stabilizing the control of the economic system through human component. The environmental protection awareness at this stage stimulated the development of environmental strategies by the government and institutions that played a key role in the emergence of the concept of green economy[2] and sustainability.

The third stage started in 90's when Pearce and Turner coined the term "circular economy" by stating that Earth is a closed economic system in which economy and environment are characterised by a circular relationship instead of linear interlinkage where everything is an input of everything else. They also mentioned entropy as the physical obstacle in the way of redesigning the economy as a closed and sustainable system. Since its inception CE has been enriched through multiple concepts such as regenerative design, industrial ecology (12,13), Cradle to Cradle (14) looped and performance economy (9) etc.

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[1] It can be described schematically as a sequence of processing stages between extraction and ultimate disposal, with a number of actual or hypothetical intermediate loops that would permit the system to be closed with respect to mass flows (Ayres, 1989)

[2] United Nations Environment Programme (UNEP) has defined it as the one that results in improved human wellbeing and the social equity while reducing the environmental risks and ecological scarcities. (UNEP, 2011)

The circular economy has gained tremendous attention of the academic researchers in last few years which is evident from a large number of reviews published on the topic in last few years (15–18). The major topics discussed in relation to CE include; the circular business models (19), closed loop and supply chains (20–22) product design (23).

The concept has also received the attention of policy makers, governments and intergovernmental agencies at local, regional, national and international level (24). Germany was the pioneer in incorporating the concept of CE into national laws with the enactment of “Closed Substance Cycle and Waste Management Act” in 1996. This trend was followed by Japan in 2002 with the formulation of “Basic Law for Establishing a Recycling-based Society” and by China in 2009 through “Circular Economy Promotion Law of the People’s Republic of China”.

- ***Conceptualisation of Circular Economy on the basis of Definitions***

The definitions of Circular Economy developed over time. The prominent trends in the definitions are demonstrated in Table 1.

Table 1 Trends in CE definitions

Author year	Definitions
Theme 1-Replacement of the linear economic system with closed loop	
Yang and Feng 2008	Circular economy is an abbreviation of “Closed Materials Cycle Economy or Resources Circulated Economy” (…) “The fundamental goal of circular economy is to avoid and reduce wastes from sources of an economic process, so reusing and recycling are based on reducing.”
Geng and Doberstein, 2008	“mean the realization of a closed loop of materials flow in the whole economic system.” (…) “implying a closed-loop of materials, energy and waste flows”.

Peters et al., 2007	"The central idea is to close material loops, reduce inputs, and reuse or recycle products and waste to achieve a higher quality of life through increased resource efficiency.
Yuan et al., 2006	“Although there is no commonly accepted definition of CE so far, the core of CE is the circular (closed) flow of materials and the use of raw materials and energy through multiple phases.”
Theme 2- Sustainable economic development	
Geng et al., 2009	“The concept of CE has the same essence as industrial ecology, implying a closed-loop of materials, energy and waste flows . . . It presents a new concept of more sustainable urban economic and industrial development.”
Park et al., 2010	“The Chinese CE policy originated with the IE policy and is built upon the concept of industrial supply chain loop closing”.
Hass et al., 2015	The circular economy is a simple, but convincing, strategy, which aims at reducing both input of virgin materials and output of wastes by closing economic and ecological loops of resource flows.
Ma et al., 2014	A circular economy is a mode of economic development that aims to protect the environment and prevent pollution, thereby facilitating sustainable economic development.
Ma et al., 2015	CE is specifically based on both resource efficiency and eco-efficiency, and its purpose is to acquire a set of key measures to move towards a more circular, green, and sustainable economy.
Theme 3-Derived from the CE concept of Ellen McArthur	

Ghisellini et al., 2016	"Circular economy is defined by Charonis (2012), in line with The Ellen Macarthur Foundation vision (2012), as a system that is designed to be restorative and regenerative.”
Hobson, 2016	The CE has been defined as an industrial system that is restorative or regenerative by intention and design….and aims for the elimination of waste through the superior design of materials, products, systems and business models.
Moreau et al., 2012	A circular economy is restorative and regenerative by design…that preserves and enhances natural capital, optimizes resource yields, and minimizes system risks by managing finite stocks and renewable flow.
Niero et al., 2017	The circular economy, defined as a restorative or regenerative industrial system by intention and design.
Theme 4- CE over the Supply Chain	
Murray et al., 2017	“The Circular Economy is an economic model wherein planning, resourcing, procurement, production and reprocessing are designed and managed, as both process and output, to maximize ecosystem functioning and human well-being.”
Naustdalslid, 2017	‘The term “circular economy” as mentioned in these measures is a generic term for the reducing, reusing and recycling activities conducted in the process of production, circulation and consumption’.
Blomsma and Brennan, 2017	Circular economy is a general term covering all activities that reduce, reuse, and recycle materials in production, distribution, and consumption processes.

There are a few trends that are obvious in these definitions. In the beginning, definitions focused on the replacement of the linear economic system with closed loop of material, energy and waste flow through reduced input, reuse, recycle (the 3R's concept) to achieve resource efficiency as can be seen from definitions by (25–28).

After that definitions added the concept of the sustainable economic development by focusing mostly on the environmental protection (29–34) which is mentioned as the concept of closing the economic and ecological loops of resource flow. The linkage of CE to sustainability is not new rather it acted as a stimulus for the initiation of the CE concept as expressed by Boulding and Pearce and Turner who suggested that sustainability requires circularity in the economic system. This dimension has become most important with the growing importance of Sustainable development Goals (SDGs) set by United Nations in 2015. In the context of Food waste management, reducing food loss and food waste is critical to creating a Zero Hunger world and reaching the world's Sustainable Development Goals (SDGs), especially SDG 2 (Z Hunger) and SDG 12 (Responsible Consumption and Production) FAO (1).

The major contribution in this dimension is made by the Ellen MacArthur Foundation that described CE as the "industrial system that is restorative and regenerative by intention and design" (35). This definition indicated the need for a systematic shift and innovation in the economic and industrial system ranging from the design of the product to the restoration and value creation after the end of life of the product.

Since 2012, the CE definitions are derived from the idea of CE given by the Ellen MacArthur Foundation and this trend can be observed in the definitions given by (16,36,37).

The Circular Economy definitions have shown rapid development and diversity during the last few years as presented in Table 1. Some of the recent definitions have addressed the 3R's concept in the production, distribution and consumption processes (38,39) whereas (40) extended the definition by describing CE as the economic model with planning, resourcing, procurement, production and reprocessing of output/processes to maximize the ecosystem functioning and the human wellbeing.

Other trends observed are; the extension of the 3R's (reduced input, reuse, recycle) concept of CE to 6R's by enriching with repair, refurbishment and remanufacturing (41), the development of long-lasting design of the product to extend the product life (9), operation at multiple levels such as micro, meso and macro (42) to achieve the long term sustainability referred as the balanced integration of economic, environmental and social aspects (24). This concept is further extended in the form of nine circular strategies (8) presented as (R1-R9) in the following figure.

In waste management systems CE is going further ahead towards the circular bio-economy. In circular bioeconomy the unavoidable fraction of food waste creates the huge opportunity for the bio conversion in useful materials (such as chemicals, fertilizers) and energy (biofuels and electricity).

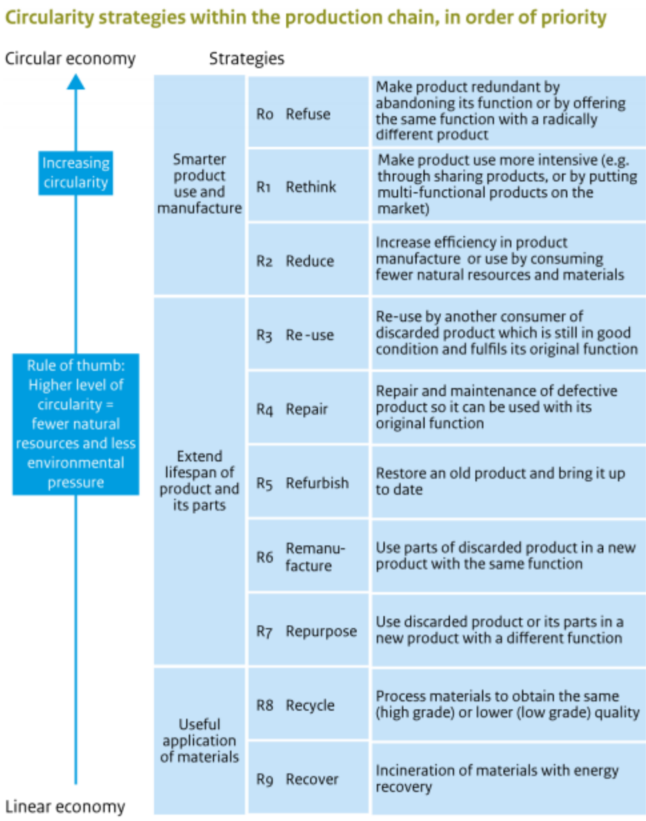

Figure 1 Circular strategies in the production chain (Source: Potting et al., 2017)

3. Sustainability, Triple Bottom Line (TBL) and CE

The concept of sustainability is derived from the French verb soutenir, which means “to hold up or support” (43) and its modern conception has its origins in forestry based on the “silvicultural principle” and was already written in early 18th century in “Sylvicultura oeconomica”. There seem to be some older sources following the same principle used for the shortage of wood supply and husbandry of cooperative systems.

Despite its existence since the 18th century, the concept of Sustainability has gained prominence since the global scale environmental risks (including climate change, the ozone depletion, biodiversity loss and the change in the biogeochemical cycles) have been identified in the 20th century. These risks have been analysed since the 1960's, raising questions as to whether the current sociological trends can be upheld in the future (44,45) subsequently causing many issues for concern, such as the limitation of resources and the way in which they are unevenly distributed geographically as well as occupationally (46).

The Brundtland Commission defined sustainability as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs".

The negative impacts of increasing population, consumption, technology and economic growth on the environment and human well-being gained considerable attention of the scholars who highlighted the role of science, technology and innovation for initiating social inclusion and environmental resilience in the economic development. This literary inclination led to the development of the present concept of sustainability.

Although sustainability was initially driven by environmental concerns, it has combined a variety of concepts and accommodated a range of expectations for desirable progress (24). The most relevant fusion in the term is the triple bottom line principle of Elkington (1997) consisting on 3P's: Profit, People and Planet (47) which he particularly coined for the corporate world. Elkington (1997) proposed TBL as the concrete tool for the companies who committed themselves to sustainable values. Although three aspects of sustainability – environmental, social and economic – existed already but this approach played a crucial role for shaping initiative towards corporate social responsibility, climate change and fair trade (48).

After the World Summit 2002 (49), it was considered as the balanced combination of social, environmental and economic performance. These three dimensions are systematically interlinked and continuously and mutually influence each other. In other words, these three dimensions are “interdependent and mutually reinforcing pillars (50), that are adaptive to a broad range of context and time horizons (51). According to (52), sustainability is “the designing and employing human systems as well as industrial systems in order to use natural resources and to make sure that the normal cycles do not have a negative impact on social conditions, human health and ecosystem”.

Based on these views it can be deduced that triple bottom line is embedded in the sustainability as TBL’s three pillars: people, profit and planet are analogous to environmental, social and economic aspects of sustainability.

However, the limitation of the TBL is that it does not protect the human and natural capital (53) and also lacking the fourth pillar of sustainable economic approach (that accounts for the future-oriented dimension of sustainability) (54). Based on this concept and keeping in view the flexible, adaptive and holistic nature of sustainability it can be stated as “ the balanced and systematic integration of intra and intergenerational economic, social and environmental performance” (24).

Sustainability is a broader concept than TBL and is not just confined to setting common operational goals in three dimensions (economic, environmental and social) rather it opens up the scope for multiple aspects such as what should be developed, what should be sustained, for how long and whom should it benefit.

Circular strategies, proposed for transition to circular economy, contribute towards reducing the consumption of natural resources and virgin materials and consequently fewer environmental effects by introducing innovation across entire network system of supply chain (economical, technological, political, socio-institutional and environmental among others) (8) that lead to transformation of the societies and economies toward sustainability. Therefore, in terms of relationship between CE and sustainability we can say that CE is means and sustainability is an end.

- ***TBL and Sustainability in Food Waste Rethinking***

Food loss and waste (FLW) is an issue in economic, environmental and social terms (triple bottom line) that pose a challenge for food sustainability. FLW is a significant economic loss in terms of time and resources (agriculture inputs and associated cost) invested on the production and food supply chain. Reducing food loss and waste have a significant impact on savings (time and resources) throughout up streams and down streams on the food supply chain (55). Initiatives taken to reduce the food loss at its roots are beneficial for producers who aim to have a high volume of sales as well as for consumers who could have access to economical food (56). However, there is a lot of criticism and debate in the literature about extra operational cost linked with managing food surplus.

Regarding the food loss and waste impact on environment, it is evident that a high level of agricultural inputs such as fertilizers and water are used to produce, process, transport and deliver food to make it available for end user. Food loss and waste is also a waste of resources such as water, energy, land and other inputs. All those actions which help to manage the surplus food as well as preventing its generation are directly or indirectly contribute towards reducing the burden on natural resources. Moreover, the positive attitude towards prevention of food loss and waste can have a considerable impact on society.

Reduction in food loss and waste pledge towards a better and enhanced food security system which extends its benefits for end users.

For example the redistribution of surplus food by food banks or food aid organisations provide food to the people who otherwise have no access to nutritional food and avoid the food waste (5) that create a positive social impact.

The total food wasted every year could feed one in nine people all over the world, who have low income or suffer from food hunger, especially in developing and third world countries. In terms of sustainability there is a need to create awareness about the "food paradox", i.e. the waste of food in a world that is still food deficient (FAO 2021) that will serve as social driver to reduce the food waste. Moreover, food production and consumption exploit the environment through resource utilization and waste generation therefore sustainable production and consumption are vital for sustainable development (SDG-12). Sustainable production leads to sustainable consumption that is viewed as satisfying customers need by reducing the negative impacts on environment. CE is a link between Sustainable production and sustainable consumption (57) that aims to avoid and minimize product and resource consumption through multiple material loops (42).

In addition to food surplus, reuse and recovery of material (such as agriculture material residue) wasted along the supply chain is crucial for fostering the CE practices in the food sector. Waste of residues in many agricultural productions causes serious sustainability problems because of their production in large quantities in limited time period and being of a particular organic matter.

Based on the concept of reuse and recovery of nutritional benefits of residues, a new frontier of agri-food research is emerging that is related to the reuse of waste and by-products to increase the nutritional power of food or its shelf-life extension (58,59). A new term of waste-to-value (WTV) products is used for these novel food products (58) to highlight the circular bio economy approach that transforms wastes or surplus ingredients, obtained during the manufacturing of other foods, into new value-added food with higher nutritional properties (60). However, after the development of WTV food products, the final market uptake depends on consumers' purchase choices. Particularly, in the agri-food sector, consumer acceptance is decisive in the development of successful novel foods. Coderoni & Perito (61) described that products origin, nutritional value, consumers inclination towards the sustainable production and consumption (such as organic food) are the drivers behind buying WTV food. However, consumer income, socio-demographic characteristics and trust on the environmental and health benefits of WTV food are the potential barriers in this regard.

4. Food Waste Management Hierarchies and Circular Economy

Food waste hierarchies are developed by different authors after the Waste Framework Directive 2008/98/EC (62). The Food Waste Hierarchy (FWH) framework introduced by Papargyropoulou (6), proposed different options and the prioritization of those options based on the environmental and social aspect of food surplus and waste by giving least importance to financial aspect. According to this framework strategies for avoiding surplus food generation and strategy of reusing surplus food for human consumption possess high priority because these strategies contribute to reduce the depletion of natural resources as well as limit the negative social and ethical implications of food waste. They were of the view that food supply chain has the greatest potentials to prevent the generation of food surplus in the upstream through new infrastructures, skills, storage and transportation technologies. Garrone (5), was of the view that prevention of food waste through different redistribution and reuse strategies still targets human consumption, therefore minimizing the waste from a social perspective. Garrone (5), extended the idea of reuse and redistribution by describing different options. Reuse options include; sales with promotions and discounts, remanufacturing and repacking, sales in secondary channels as ad-hoc distributor for surplus food and redistribution covers both internal (to the employees of a company) and external channels (through the collaboration with food aid organizations). In terms of avoid or prevent strategy, Garrone (5), and Vandermeersch (63) refer to the prevention of food waste and loss but not to the reduction or avoidance of surplus food that is a distinct feature in Papargyropoulou (6), framework.

Similar to Papargyropoulou (6), framework, the Food Recovery Hierarchy by United States Environmental Protection Agency (EPA, 2012) priorities the strategy of reduction of the volume of surplus food generated at source. Rood (64), classified different redistribution and reuse options and added distinct layers in the Moerman's ladder such as converting into human food (in which food products are transformed into new edible products) in addition to human food (usually considered as redistribution in original form), raw material for industry and turned into fertilizer through fermentation.

Teigiserova (65), has provided six distinct categories in food waste comprising one edible and five inedible food categories. Based on these categories they proposed a waste hierarchy and expanded it by material recycling and nutrient recovery to reflect the future food waste biorefineries in the circular bioeconomy.

An interesting thing to note in these frameworks is that most of the frameworks have similar options in the lower parts of the waste hierarchy (such as recycling of food products into non-edible alternatives such as food for animals and fertilizers, recovery by energy generation, incineration and disposal) but some differences can be seen moving up in the waste hierarchy.

Another interesting aspect in these hierarchies is that these focus primarily on managing food surplus, harvesting losses considering those unavoidable and food loss and waste along the food supply chain but didn't account for low-yields or low productivity in the farming operations.

All these frameworks provide the application of reduce, recycle and reuse (3Rs) that support the aims of the circular economy. Table 1 provides a summary of different frameworks and their priorities of actions and relevant policies to follow for food waste management.

Table 2 Summary of food waste hierarchies presented in literature (Adapted from Cicculo et al., 2021)

Name of the framework	**Prioritisation of actions in the hierarchy (from most preferable to least preferable)**	**Reference**
Waste hierarchy food waste hierarchy	1. Prevention 2. Prepare for reuse 3. Recycling 4. Other recovery (e.g. Energy recovery) 5. Disposal	(European Commission, 2008) (Papargyropoulou et al., 2014)
Food recovery hierarchy	1. Source reduction 2. Feed hungry people 3. Feed animals 4. Industrial use 5. Composting	(United state Environmental Protection agency -EPA, 2012)
Availability- Surplus- recover ability-waste model (ASRW)	1. Recover surplus food to feed humans 2. Recover surplus food to feed animals 3. Waste recovery	(Garrone et al., 2014)

	4. Waste disposal	
Food waste management hierarchy	1. Prevention 2. Conversation for human nutrition 3. Use of animal feed 4. Use as raw material in industry 5. Process into fertiliser 6. Use as a renewable energy 7. Incineration 8. Landfill	(Vandermeersch et al., 2014)
Moerman's Ladder	1. Preventing food losses 2. Human food 3. Converted into human food (food processing) 4. Use in animal feed 5. Use as raw material in industry 6. Process into fertilizers through fermentation 7. Process into fertilizers through composting 8. Applied for sustainable energy 9. Incineration	(Rood et al., 2017)

Hierarchy for food Surplus and Waste	1. Prevention 2. Reuse -H 3. Reuse -A 4. Material recycling 5. Nutrient recovery 6. Energy recovery 7. Disposal	Teigiserova et al., 2020

5. Aligning the Food waste hierarchy with circular strategies

The food waste hierarchies used in the literature have mostly described "Reduce", "Reuse", "Recycle", and "Recover" strategies in the context of CE. However, the food waste management system can be extended to other circular strategies described in literature. In this study, we have proposed the alignment of Moerman's Ladder developed by Rood (64), for food waste management with the circular strategies suggested by potting et al., 2017 for production chain (presented in Table 3).

In the waste management hierarchy, prevention is the first priority for surplus food that is aligned with the circular strategy of "Refuse" and "Reduce" that emphasize abandoning the production if not required and reducing the consumption of natural resources. Redistribution of surplus food stated as *Human Consumption* is aligned with the circular strategies of "Rethink" and "Reuse" because food use is intensified by sharing it in its original form with the people in need (alternative channels of consumptions) that otherwise would not have access to nutritional food. The third level in food hierarchy, *Converted into Human Food*, stresses the food processing of surplus food to extend its shelf life that is in line with the circular strategies of Repair, Refurbish, Remanufacture and Repurpose that work towards extending the life of product/part with its original functionality by carrying out varying degrees of processing. All the strategies having high degree of circularity are embedded in the Food surplus management options detailed in the Moerman's ladder.

The next level in food management hierarchy is food waste that is inedible for human therefore alternative options for use are suggested to minimize it. The first inedible option is to use it as the animal food that is in line with the circular strategies of Reuse and Repurpose because the discarded inedible food is diverted to non-human consumption. The next level in waste management is the use of by products or food residues as the raw material for industries that coverts it into products with different functionality and is in line with the circular strategy of Repurpose. The next two levels (level 7 and 8 in food waste) describe the retrieval of organic nutrients from FW and reintroducing them to the ecosystem to restore the depletion of natural resources (agricultural land) that is in line with the recycling where the product remains in circulation with value addition (may be of high or low grade quality). The last two grades of food waste have value addition through recovering energy in line with the Recovery strategy of CE that is considered the least circular strategy.

The explanation above demonstrates the alignment of circular strategies with the waste management hierarchy indicating that circular strategies have the universal application for the waste management systems. In the context of food waste management systems, food surplus management by preventing excess food production and maximizing surplus consumption among human by redistribution and increasing food life through processing leads to sustainable consumption and production systems that can contribute to achieve the goals of "Zero Hunger" and "Responsible Consumption and Production".

Table 3 Alignment of circular strategies with food waste management hierarchy

<table>
<tr><th>Circularity strategies within production chain</th><th>Moerman's Ladder</th><th></th><th></th></tr>
<tr><td>Refuse (Ro), Reduce (R2)</td><td>1-Prevention (preventing food losses)</td><td rowspan="3">Edible Food</td><td rowspan="3">Surplus Food</td></tr>
<tr><td>Rethink (R1), Reuse (R3)</td><td>2-Human food</td></tr>
<tr><td>Repair (R4), Refurbish (R5) Remanufacture (R6), and Repurpose (R7)</td><td>3-Converted into human food (food processing)</td></tr>
<tr><td>Reuse (R3), and Repurpose (R7)</td><td>4-Used in animal feed</td><td rowspan="7">Inedible</td><td rowspan="7">Food Waste</td></tr>
<tr><td>Repurpose (R7)</td><td>5-Raw materials for industry (bio-based economy)</td></tr>
<tr><td>Recycle (R8)</td><td>6-Turned into fertilizer through fermentation (and for energy generation)</td></tr>
<tr><td>Recycle (R8)</td><td>7-Turned into fertilizer through composting</td></tr>
<tr><td>Recover (R9)</td><td>8-Applied for sustainable energy (purpose is energy generation)</td></tr>
<tr><td>Recover (R9)</td><td>9-Incineration as waste (Incineration/discharge with energy and mineral recovery)</td></tr>
<tr><td>Disposal</td><td>10-Landfill (Avoid if possible)</td></tr>
</table>

6. Challenges and opportunities

The above section described the circular ways of managing food waste to minimize the negative impacts on the environment alongside leveraging the societal benefits. However, this circular food waste management system presents both opportunities and challenges when put into practice in real life and need careful considerations and collaboration of academia, practitioners and policy makers to overcome the challenges and tackling the FW related financial and environmental constraints. The challenges and opportunities are categorized as technological, economical, and cultural dimensions.

- ***Technological opportunities and challenges***

Food waste is one of the biggest sustainability challenges and could be reduce by better waste management throughout the supply chain in addition to redistribution of surplus food and sustainable food management. Technology is an important resource that can play a positive role in preserving surplus food through innovative packaging and storage. In addition, the FW is an important source of energy and chemicals where appropriate technology can enable the recovery of materials and energy by disposing the FW in environmental-friendly way. FW and FL occur at all stages in the supply chain due to technical and infrastructural reasons that need technology application at large scale by having minimum environmental impact. However, the challenge is technology solutions are developed and assessed at the laboratory where large scale application require huge amount of resources. Moreover, for the recovery technology the biggest challenge is determining the product quality and hygiene that make it hard to assess the actual yield (chemical, bio gas etc.) of biomass. Therefore, government support and incentivization is necessary for the application of technology at large scale in the long run.

- ***Economic opportunities and challenges***

Food redistribution, reuse and recovery strategies feed back to the economy with additional by- products and economic benefits. Moreover, the use of food waste as feedstock reduces the cost of disposal for the industry. For biorefinery the high initial cost of set up is balanced by the availability of cheap FW feedstock. In terms of challenge, the cost of generating energy from FW (considering the availability and transportation cost) cannot be estimated precisely due to absence of real biorefinery implementations. Moreover, FW feed stock usage for generating commodities and energy can only be achieved through the development of proper incentive system by the Government and collaboration among different actors across the entire food supply chain.

- ***Cultural opportunities and challenges***

One of the benefit for the effective food management system is food surplus redistribution that provides nutritional food to underprivileged citizens by relevant associations and charities and create awareness for sustainable consumption. The food waste use for the energy generation can reduce power scarcity and the decline of wood burning in low-income countries or in the countryside (66). FW can also provide a low cost alternative for generating energy instead of using new and costly raw material. However, reducing the food surplus and food waste require substantial change in production and consumption patterns at industry and market levels that is hard to change due to complex relationship between suppliers and distributers, contractual agreements, food standards, and inaccurate food demand forecast Eriksson (67). Moreover, variable definitions of food waste hinder the development of standard regulatory metrics for the qualification. Another challenge is that the recovery technology is mostly available in the developed economies whereas the feedstock market is in the developing economies. In terms of WTV products, consumer acceptance is a crucial factor and serve as the decisive strategy for the development of such products. Substantial FW is caused at the household level that require educating individuals for zero food waste and introducing responsible consumption habits to reduce this waste.

7. Conclusion

Food waste poses the greatest challenge for sustainability of the food management systems. Circular economy is redefining the ways for waste management including the food waste and creating new business opportunities by circulating food waste into various closed loops. Food waste can be used to produce various biomaterials, bioenergy and high-value products.

A systematic literature review is conducted in the study to describe the initiation of CE and different emerging themes in the CE. Moreover, literature on the agri-food waste is explored for identification of different food management frameworks, their similarities and differences. The study also derived an alignment between the food waste management hierarchy and circular strategies of production chains. This alignment highlights that the efforts for application of food waste management hierarchy are actually a functional implementation of circular strategies that lead to achievement of food sustainability with the minimum environmental effects. The study has also explored the concept of TBL and sustainability and draws similarities and differences between these two concepts. CE is discussed as a way towards the achievement of sustainability particularly in the context of food waste management that could contribute towards the achievement of sustainable development goals of “Zero Hunger” and “Responsible Production and Consumption”.

However, there are several challenges for the food waste prevention as a sustainable waste management system in the emerging circular bioeconomy that needs standard regulatory infrastructure, Government incentive systems, collaboration among different actors in the food supply chain, cooperation between academics and practitioners and change in the way of production and consumption at individual, institutional and market levels.

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