REDUCING CONSUMER FOOD WASTE USING GREEN AND DIGITAL TECHNOLOGIES

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LIST OF ACRONYMS AND ABBREVIATIONS

AC	Alternating current
AI	Artificial intelligence
AP	Active Packaging
AOA	Anatomy of Action
BBE	Best before end
B2C	Business to consumer
C2C	Consumer to consumer
CO_2	Carbon dioxide
CO_2eq	Carbon dioxide equivalent
CSR	Corporate social responsibility
DC	Direct current
DEB	Data embedded barcode
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FLW	Food loss and waste
GDP	Gross domestic product
GHG	Greenhouse gas
H_2S	Hydrogen sulphide
ICT	Information and communications technology
IDB	Inter-American Development Bank
IFC	International Finance Corporation
IoT	Internet of Things
IP	Intelligent packaging
IPCC	International Panel on Climate Change
ISO	International Organization for Standardization
ITC	International Trade Centre
MSW	Municipal solid waste
N_2	Nitrogen
NFC	Near Field Communication
NGO	Non-governmental organisation
OECD	Organisation for Economic Co-operation and Development
PCC	Pacific Coast Collaborative
PCFWC	Pacific Coast Food Waste Commitment
P2P	Peer to peer
PPP	Public-private partnership
QR code	Quick response code
RFID	Radio frequency identification
RRR	Reduce-Reuse-Recycling
SDG	Sustainable Development Goal
SME	Small and medium-sized enterprise
UK	United Kingdom
UN	United Nations
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
US	United States of America
WBCSD	World Business Council for Sustainable Development
WHO	World Health Organization
WtE	Waste to energy
WRAP	Waste & Resources Action Programme
WRI	World Resources Institute

EXECUTIVE SUMMARY

The world is facing a food-waste crisis. It is estimated that 931 million tonnes of food were wasted by households, retailers, restaurants and other food services in 2019 [1]. Around 61% of this waste occurs within households.

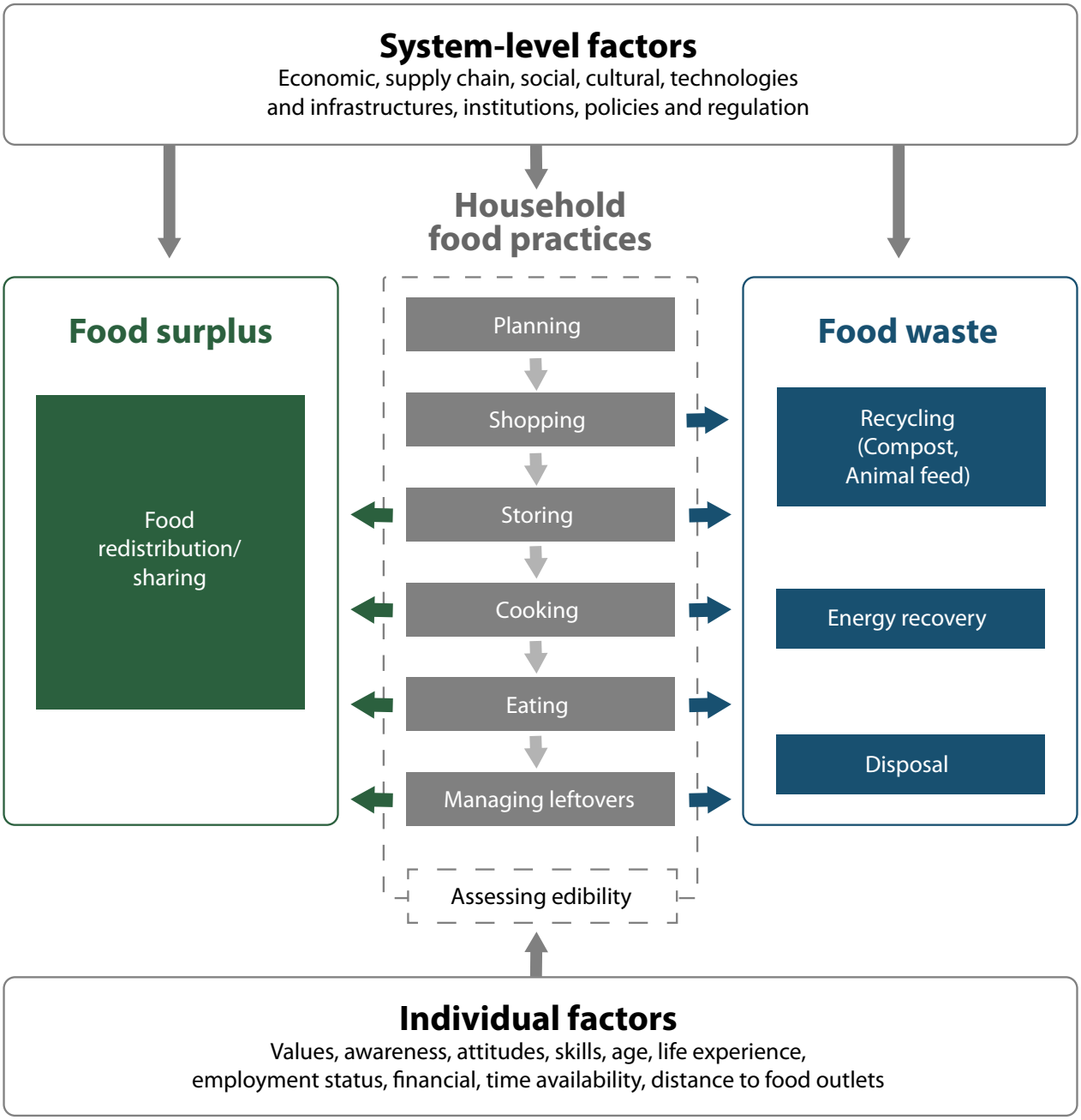
Reducing food waste offers multiple benefits for people and the planet, contributing to improving food security, cutting pollution, saving money, reducing the pressures on nature and climate, and creating opportunities for economy and society. It is for this reason that the UN's Sustainable Development Goal (SDG) 12.3 sets a clear target of halving per capita global food waste by retailers and consumers by 2030.

The UN Food Systems Summit in 2021 highlighted innovation as the key to transforming the way food is produced and disposed of. Green and digital technologies are playing an increasing role in reducing consumer food waste and driving food consumption towards more sustainable patterns. Cities in both developed and developing countries are well positioned to harness new opportunities arising from green and digital technologies.

This report provides an overview of the causes of consumer food waste and the opportunities for reducing it through different means: behavioural change, technological solutions, and public and private initiatives to mitigate the problem. This study aims to improve understanding of how green and digital technologies could be used to reduce consumer food waste and what could be done to further unlock this potential. By combining global research cutting across multiple disciplines with city case studies, it aims to provide a comprehensive and integrated approach to support countries and cities in combating food waste and in 'Building Back Better' a more sustainable economy.

Key findings and messages

- **Consumer food waste is driven by intertwined factors at multiple levels** (individual, household, society) **embedded in everyday practices.** These factors include attitudes, knowledge, skills, values, gender, income and living standards, markets, prices, and social and cultural practices, among others. Food-waste interventions thus need to take full consideration of how different factors affect the social practices (e.g., household food practices) that make up peoples' everyday lives.
- **There is a large gap in data and in assessing consumer food waste,** including current status, its economic, social and environmental costs, and future trends. Data for cities is even scarcer, making it difficult to diagnose the problem. None of the five cities covered in this report (Bangkok, Belgrade, Bogotá, Doha and Kampala) has official data systems to measure and analyse consumer food waste. Better data is urgently needed to improve our understanding of consumer food waste, to support the design and implementation of targeted interventions, and to track progress in achieving related SDG targets.
- **Green and digital technologies are increasingly being used to prevent, reuse and recycle food waste, opening new opportunities for economy and society.** Examples include technologies and innovations in thermal preservation, biological and bio-chemical preservation, solar-powered cold storage, active packaging, waste-to-energy, composting, recycling and upcycling. Emerging digital technologies such as the Internet of Things and mobile applications provide innovative solutions for food-sharing, smart labelling, dynamic pricing, product traceability, intelligent redistribution, planning of shopping and meals, and storage. The list is non-exhaustive, and some measures concerning them have been implemented in the five cities covered in this report.



Food surplus and food waste are generated through households' everyday food practices. Factors at the individual, food-system and social levels influence these practices and the management of the food surplus and waste.

PREVENTION		
Type	Function	Description
Green	Thermal preservation	*Refrigeration and cold chains*
	Biological and bio-chemical preservation	*Use of essential oils and natural extracts in active packaging*
Green + Digital	Smartphone apps: Food planning, shopping, storage & cooking	*Guide, track and inform consumers in food related choices to reduce food waste*
Green + Digital + IoT	Smart packaging	*Use of sensors and data carriers to monitor food quality*
	Smart labelling	*Use of data embedded barcodes (DEB) to improve information about food quality*
	Smart storage and disposal	*Wifi connected fridges and bins equiped with cameras and sensors to monitor food quality and food quantity*

RE-USE		
Type	Function	Description
Green + Digital	Smartphone apps: Food sharing and redistribution	*Different types of food sharing apps: Sharing for money, sharing for charity or sharing for the community*

Overview of the green and digital technologies addressing food surpluses covered in the report.

- **Most of the green tech solutions face challenges in upscaling and going beyond the 'niche market'.** Findings from the five cities, as well as globally, have shown that there is a lack of data on the cost savings and environmental and social benefits of adopting green and digital technologies in reducing food waste. For many developing countries, hurdles remain in accessing such technologies, securing investment and financial resources, driving demand, raising awareness, and building the capacity and skills needed to deploy and manage such technologies effectively.

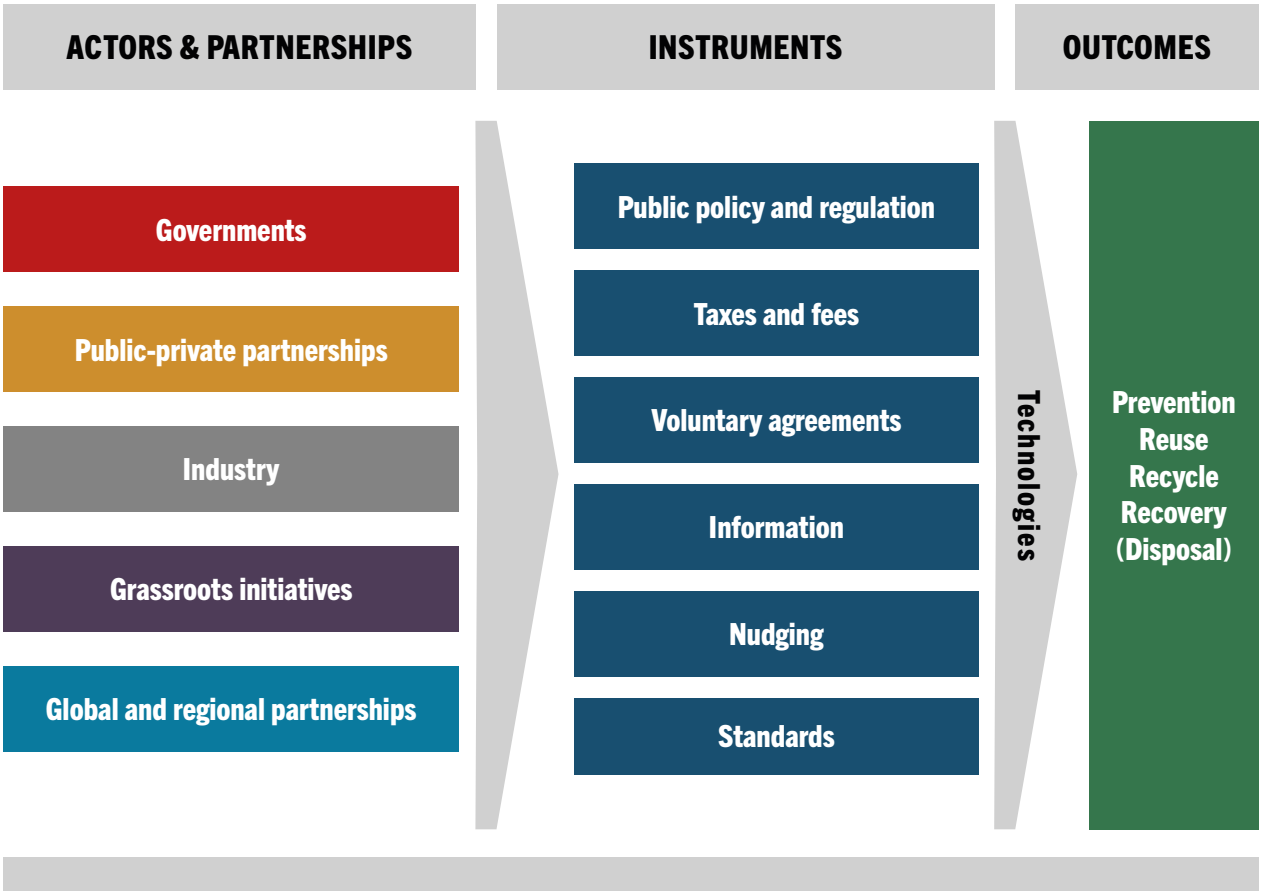
- Technologies alone will not solve the food-waste problem. Instead, applied in the right way, they can work as a powerful enabler and accelerator to support initiatives and instruments led by different actors and partnerships. They also require an enabling environment to thrive and to fully unlock their potential in reducing consumer food waste. **A comprehensive and integrated approach is therefore needed that links technology, policy, regulation, incentives, infrastructure, information and behavioural science in a way that makes them mutually supportive and complementary to each other.**

- **Governments are crucial in setting targets, ensuring accountability and providing incentives and support for businesses and consumers to take actions.** This can be done through regulations (standards, bans, mandatory requirements), market-based instruments (e.g. taxes, fines, subsidies) and providing waste-management infrastructure (collection, composting, recycling) and capacity support (knowledge, finance, information). While all five cities have put forward policy frameworks for reducing food waste, there is a need to combine long-term strategies and road-maps with short-term targets and concrete measures locally to ensure effective implementation. More also needs to be done to remove incentives that have the perverse effects of preventing or discouraging actions to reduce food waste.

- **Food processors, distributors, retailers and food-service providers, as well as green tech innovators, play a decisive role in influencing consumers' food-waste behaviour.** Champions and pioneers are leading the way in the five cities and other places in the world in entering into voluntary agreements between supply-chain operators, retailer-supplier contracts, traceability systems, closed-loop circular models and public-private partnerships. Good practices and scalable approaches could be further analysed and shared for peer learning and replication. More support is needed for small and medium-sized enterprises (SMEs), local food vendors and community-based service providers in the informal sector, all of whom play an important role in waste collection and management in developing countries.

- **Grassroots initiatives led by communities and individuals have proved to be effective in changing people's perceptions and behaviour related to food waste.** Examples in the five cities include awareness-raising campaigns through social media channels, online and offline education and training programmes, and digital platforms for voluntary sharing and exchanging surplus food. Novel approaches were also piloted in some cities to link reducing food waste with food donations, urban farming and campus events.

- **Consumer preferences and choices can influence business and government decisions on food waste, and consumers can contribute to wasteless, sustainable food systems if they are aware, motivated and empowered.** Substantial shifts towards sustainable consumption and lifestyles can spur demand for more sustainable food products, services and innovations in policy and business practices. This report emphasizes that sustainable food and food systems are not just about benign production methods, but also about how food is used and disposed of at the end of its life-cycle. For consumers to have an impact on sustainable food systems in this broader sense, there is an urgent need to raise their awareness of the food-waste crisis, including the environmental and social consequences of unsustainable food consumption, but also what actions they can take to reduce their own food waste. Yet, while motivating consumers and raising their awareness is necessary, it is not sufficient, but must be complemented with initiatives that enable and empower consumers to change behaviour through the provision of resources, opportunities and abilities.



The main building blocks of food-waste interventions: actors and partnerships, the mix of instruments used, and the role of technology in enabling and accelerating the interventions and outcomes in relation to the food-waste hierarchy.

- **There is growing evidence of success in using an integrated approach with a mix of different instruments and active engagement with multiple actors and stakeholders along the food value chain to reduce consumer food waste.** Top-down and bottom-up approaches can complement each other in unlocking the potential of green and digital technologies to achieve the expected results. This offers great opportunities for cities to transform themselves from food-waste hotspots into innovation hubs that can pilot and showcase successful models and partnerships to tackle the food-waste challenge.
- Design and implementation of food-waste interventions need to be **tailored to local circumstances** and take fully into account **social and cultural factors** such as values and norms, gender, food security, health and equality to ensure their success and impacts.

1. STATE OF FOOD WASTE AND ITS CONSEQUENCES

In 2019, 931 million tonnes of food were wasted globally by households, retailers, restaurants and other food services, amounting to 17% of the total food available to consumers according to estimates in UNEP's Food Waste Index Report [1]. This waste is occurring while 690 million people are affected by hunger, and three billion are unable to afford a healthy diet, numbers which have been rising sharply under COVID-19. Global annual waste generation is expected to rise from 2.01 billion tonnes in 2016 to 3.40 billion tonnes over the next 30 years, a trend that is especially strong in developing countries in Asia and Africa [2]. Food-waste generation can be expected to follow a similar trend and geographical pattern unless concerted action is taken.

The substantial amount of food that is lost and wasted every year also has major environmental implications in terms of climate change, loss of biodiversity, freshwater, marine and air pollution, and the use of land and water resources [3]. According to the Intergovernmental Panel on Climate Change (IPPC), combined food loss and waste amount to 25–30% of total food produced (*medium confidence*), representing close to 30% of the world's agricultural land area [3], and equivalent to an area greater than China. In addition, food production that ends up as food loss or waste consumes a quarter of the world's agricultural freshwater use and generates 8-10% of total anthropogenic greenhouse gas emissions [4]. Moreover, an estimated 70% of biodiversity loss stems from agriculture and the cultivation of food, fuel and fibre, suggesting that food loss and waste contribute significantly to the decline in plant and animal species. In terms of economy, according to the Food and Agriculture Organization (FAO), the costs of food loss and waste totalled US$ 1 trillion per year at 2012 prices, with environmental costs amounting to US$ 700 billion and social costs to US$ 900 billion [1].

This makes food loss and waste a key action area for sustainable development, as well as economic efficiency.

This report focuses on one part of the 'food loss and waste' problem, namely food waste that occurs at the downstream **retail and consumption stages** of the food supply chain where consumers interact directly with food, i.e. at the level of household, retail and food service provision by restaurants, in catering, hotels, school/work canteens, etc., We use the term '**consumer food waste'** as a shorthand for waste generated in this part of the food system. Hence, this report does not consider food loss, which occurs in the earlier stages of the supply chain (farming, processing, wholesale). However, we emphasize that the focus on consumer food waste does not imply that the cause of, or responsibility for, the food waste is necessarily to be found in this part of the food system. This is why we have adopted a multi-level and integrated approach (see section 2.4).

Consumer food waste is understood as food meant for human consumption that completes the food supply chain up to a final product but is not consumed because it is discarded. The notion of food waste covers the decrease in both the quantity and quality of food.

The report examines the causes of food waste and the opportunities for food-waste reduction through different means: behavioural change, technological solutions, and public and private initiatives to mitigate the problem. Food-waste reduction in this report refers to activities that either address the food surplus through prevention or re-use, or that improve the management of so-called unavoidable food waste through recycling, recovery, or engineered landfill, where prevention and re-use are the preferable options (see section 1.3).

Food-waste reduction is an emerging and urgent policy field in which experience is relatively scarce. The opportunities for food-waste reduction are widely untapped and under-exploited. Failures of data, knowledge and attention have been important causes of this inaction by governments and companies in the food system alike. In particular, knowledge about consumers and their behaviour and conditions in relation to food waste is lacking. A better understanding of how and why individuals consume and waste food at home, in school, at work or in restaurants is central for governments' and businesses' strategies, decisions and initiatives aimed at enabling and incentivizing more sustainable consumer behaviour.

This report aims to provide a clearer picture of, on the one hand, consumers' behaviour and everyday practices with respect to food waste and, on the other hand, the opportunities governments, private businesses, civil society and consumers have to change the direction of the current food system and create a new path with less food waste through new and innovative interventions and partnerships. Moreover, the report provides an overview of the green and digital technology landscape related to food-waste reduction, arguing that technologies can widen the playing field and enable and accelerate the development towards waste-free food systems.

1.1 State of food waste at the consumer level

The consumer level accounts for a large part of the food waste in all regions and warrants more attention. In West Asia, for example, around 34% of the food served is wasted, with an estimated 100 to 150kg/cap of food waste occurring at the household level, according to a recent UNEP survey [5]. High rates of organic household waste have also been observed in cities in West Africa [6,7] and in other regions.

Table 1.1. Average food waste by World Bank income classification.

Income group	Average food waste (kg/capita/year)		
	Household	Food service	Retail
High-income countries	79	26	13
Upper middle-income countries	76	Insufficient data	
Lower middle-income countries	91	Insufficient data	
Low-income countries	Insufficient data		

There are relatively small differences in household food waste between countries at different income levels, with lower-middle-income countries having the largest rates. Source: [1]

The UNEP Food Waste Index Report [1] identified 152 food-waste data points in 54 countries, the largest global food-waste dataset collected to date. It found that in nearly every country that has measured food waste, it is substantial, regardless of the income level of the country (Table 1.1). Lower-middle-income countries have higher waste rates than countries with higher income levels. This is a surprising finding because previous narratives suggested that household food waste was a problem limited to high-income countries, leading to slower action in middle- and lower-income countries than would be merited.

A small number of countries, such as the UK and the Netherlands have been successful in reducing household food waste substantially: for example, the UK achieved an 18% reduction in food waste between 2007 and 2018 [8]. However, many more countries need to start measuring and tracking the generation of household food waste by conducting research to understand local causes and solutions, and to develop national food-waste reduction strategies and programmes encouraging behavioural change.

1.2 Implications for the SDGs

Sustainable Development Goal 12.3 calls for a halving of food waste by retailers and consumers and a reduction of food loss across supply chains by 2030. The delivery of this target helps countries reach numerous other SDGs, from Zero Hunger to Climate Action, including Life on Land, Life under Water and Sustainable Cities.

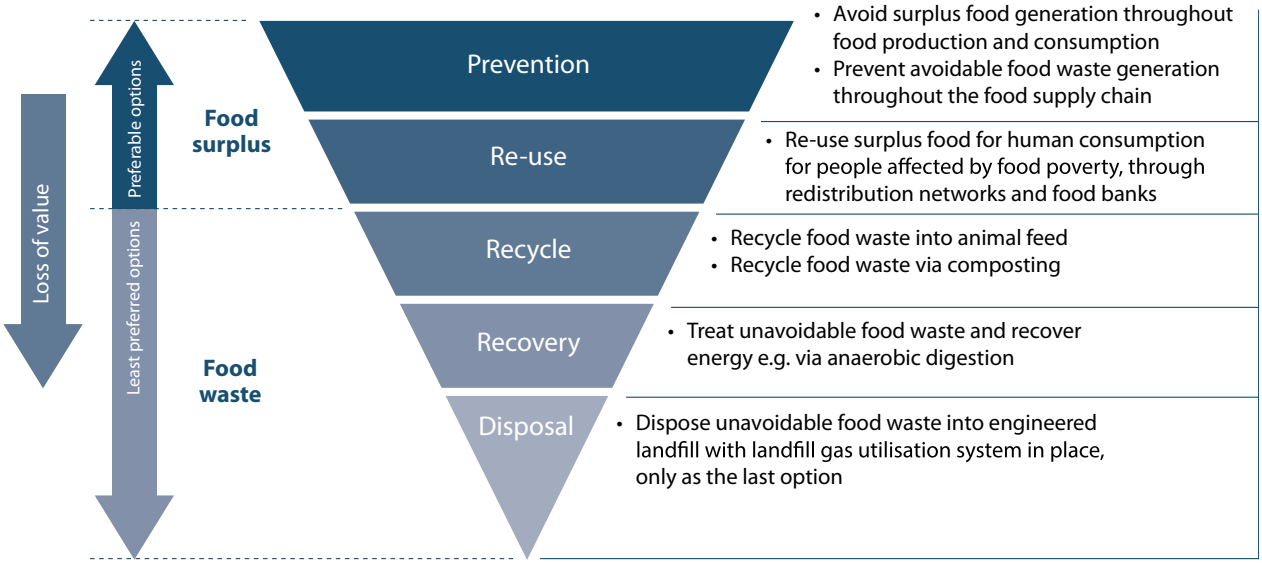
Food waste affects several environmental, economic and social SDGs. Food-waste prevention and recycling efforts can create jobs and incomes, but associated costs and benefits may be unequally distributed across genders, age groups and social classes. The UN Food Systems Summit 2021 identified four 'levers of change' that have the potential to deliver wide-ranging positive change beyond their immediate focus, which can bring about significant progress in both the transformation of food systems and the achievement of the 17 Sustainable Development Goals (SDGs) [9]. One of the four levers is gender equality and women's empowerment, including through 'economic empowerment of women in food systems; women's leadership in food systems; access to technologies (including digital); changing norms and addressing institutional barriers; and gender-responsive agricultural and food systems policies.' A second lever of special interest to this report is innovation, the emerging areas of focus being data and digital, scientific and technological, national and regional innovation ecosystems, as well as societal and institutional innovation models, including traditional and indigenous knowledge [9].

COVID-19 has affected patterns of food consumption and waste that could have lasting effects, which future food-waste prevention and recycling initiatives should consider. This is evident from several studies [10–13] and from a recent survey in West Asia [5]. It also forced people to rethink the way food was produced and consumed (see Chapter 2).

1.3 The food-waste hierarchy

To address the enormous problem of food waste, one scheme of prioritized actions is illustrated by the notion of a food-waste hierarchy [14,15] (see Figure 1.1). The *prevention* and *re-use* (in that order) of **food surpluses** have the highest priority, and include the reduction of overall food being wasted throughout the supply chain and the redistribution of surplus food that otherwise would have been wasted for human consumption. The next priority is to manage so-called unavoidable **food waste** in ways that ensure either the *recycling* of the food's energy and minerals/nutrients for animal feed (preferred), or of the minerals/nutrients through composting. An alternative option is *recovery* of the food's energy content through energy conversion such as anaerobic digestion and the use of the digestate (containing nutrients and minerals) for fertiliser. The least preferred option in the hierarchy is *waste disposal* in engineered landfills that safely manage gas and other pollutants. In general, the longer one moves from prevention towards disposal, the more economic value is lost, reminding us that opportunities exist for achieving synergies between environmental and economic objectives under the right conditions.

Figure 1.1. The food waste hierarchy. Source: adapted from [14].



In this report, we focus on food-waste prevention and re-use as the preferred options for tackling food waste at the level of the household, retail and food service provision. We also address the recycling and recovery of non-edible food, which is still a challenge in many countries. Low- and middle-income countries in particular have an opportunity to leapfrog into a prevention and re-use regime (see Chapter 2), thereby reducing the cost of building waste-recycling systems [16], which would only need to handle non-edible fractions.

The food-waste hierarchy is well aligned with the principles of a circular food system. Circular food systems prioritize regenerative production, reduce resource inputs and pollution, and ensure resource optimisation in a system where 'waste' does not exist because by-products and side-streams from one cycle are used as feedstock for another cycle. In a circular food system, food-waste prevention and re-use are priorities, as they provide the greatest benefits in terms of food security, greenhouse gas emissions and savings of natural resources. Circular food systems also maximise the opportunities for recycling unconsumed food safely into animal feed or using it in the production of biomaterials, organic fertilisers or bioenergy according to local contexts and priorities.

1.4 Cities as major hotspots of consumer food waste

The rapid development of large cities and urban areas is increasingly affecting the environment. Cities in both developed and developing countries face mounting pressure from the accelerating generation of food waste by households, retailers and food service sectors. Growing populations, urbanization and dynamic economic and social activities in urban areas are likely to fuel the food-waste problem further. It is estimated that by 2050, 80% of all food will be consumed in cities [17]. The city case studies presented in this report show that food waste already takes up a big portion of municipal solid waste (MSW), adding an extra burden to the waste management system and leading to environmental and social problems [18,19]. At the same time, urban consumption patterns and food supply chains are rapidly changing [20], making food-waste reduction in urban settings an urgent issue.

Yet cities can also be hubs for innovative solutions to the food-waste challenge. With active interconnections among public entities, businesses, academia and civil-society groups, cities are well positioned to harness opportunities arising from transformations in technology, economy and society [21].

1.5 The role of green and digital technologies

The urgent challenges of food waste represent an open window for technological innovations, which are relevant at all stages in the food value chain and are receiving increasing attention as such. The adoption of different technological solutions can improve vertical collaboration between the adopter of the technology and other actors in the value chain in order to reduce food waste [22]. Technological innovations can address waste prevention and re-use or support the valorisation of unavoidable food waste through recycling or recovery.

Technologies to address food-waste prevention and re-use at consumer level have different objectives: extend the shelf life of food products; reduce the generation of surplus food in retail, households, restaurants etc.; and increase and make more efficient the redistribution of surplus food. Food-waste reduction technologies thus include food preservation technologies, food packaging and smart labelling, consumer-oriented smart devices or consumer and food-sharing apps (see Chapter 3).

Many of these technologies are still rather immature, their development being characterised by early-stage experimentation, proto-typing or limited roll-out. Competences and key technical expertise related to adopting and implementing new technologies often lie outside the food supply chain and therefore require new types of collaboration with technology providers and new or modified business models [22].

There is also a lack of data on the economic, environmental and social benefits of adopting green and digital technologies in relation to food waste. Research conducted by the World Business Council for Sustainable Development (WBCSD) found that, for every US$1 companies across a wide range of sectors (e.g., food manufacturing, food retail, hospitality and food service) invested to reduce food loss and waste, they saved US$14 in operating costs [23]. Household savings could be much greater. Such information about cost savings could help make a stronger business case for those green and digital technologies.

The uptake of new technologies can nevertheless be perceived as costly and risky for the individual company in the various food sectors. Therefore, although the emerging technologies show promising results and bring the hope for successfully addressing food waste at the consumer level, technological innovations cannot stand alone. To fully unlock their potential in food-waste reduction, an enabling environment is needed that connects policy, infrastructure, finance and behavioural changes among consumers in order to reduce the risk to individual companies of engaging in the uptake of new technologies.

Box 1.1. Definitions of green technologies and digital technologies

Based on UNEP's conceptualisation of environmentally sound technologies [24], in this report 'green technologies' refers to those that have the potential to significantly improve environmental performance relative to other technologies. Green technologies protect the environment, are less polluting, use resources in a sustainable manner, recycle more of their wastes and products, and handle all residual wastes in a more environmentally acceptable way than the technologies they replace. The term 'technology' refers here not just to individual technologies or technological concepts, but also to technological systems that include know-how, procedures, goods and services, infrastructures and equipment. Green technology also encompasses organizational and managerial procedures for promoting environmental sustainability.

Digital technologies are electronic tools, systems, devices and resources that generate, store or process data.

Photo credit: Shutterstock

1.6 About this study

This report is one of the key outputs of the project 'Using Green and Digital Technologies to Reduce Food Waste at Consumer Level' led by UNEP and implemented in 2020 to 2021. The overall objective is to support countries in developing or adapting policy frameworks that support the specific technologies that can reduce resource use and pollution, contribute to the attainment of the SDGs and climate goals, and Build Back Better from the COVID-19 pandemic. The project and the report bring together research at the global level and case studies from cities to provide a comprehensive and integrated approach cutting across policy, economics, technology and behavioural science.

This report includes as many as possible insights about food waste-generating factors from countries at all income levels. Nevertheless, there is relatively little research from developing countries on food waste at the consumption stage of the supply chain. A literature review from 2017 identified 292 downstream food-waste articles from 2006 to 2017, including 48 countries or geographical regions [25]. Most articles (n=53) reported on global or multi-country studies, followed by USA, the UK, Sweden, Italy and the whole EU. China with 13 articles was the only developing country in the top 10 countries or regions studied. A large increase in publication intensity over time was also observed for most other regions, and the review found that 'countries that had an early identification of food waste as a social problem (including USA, UK and, Sweden) continue to publish prolifically' [25].

Since 2017, research on food waste from low- and middle-income countries has intensified. For example, the first study quantifying household food waste in Iran was published in 2019 [26]. It found that households' food-waste generation and management in Tehran city were determined by direct and indirect factors operating at multiple levels [26]. The study highlights that consumer food waste is the result of a complex relationship between these factors, internal and external to consumers and associated with various levels of intervention. Studies and literature reviews from several world regions (Asia, Latin America, the Middle East, and North Africa) confirm that research on consumer food waste is growing across the world [27–29].

2. UNDERSTANDING THE CAUSES OF CONSUMER FOOD WASTE

The causal mechanisms and factors influencing consumer food waste are manifold and complex. Recent reviews have gathered long lists of potential factors at the individual and societal levels and assessed their effects on consumers' food-waste behaviour [30–32]. However, this research is often inconclusive because consumer food waste cannot be attributed to single variables [31]. Instead, it must be understood – and addressed – by considering the inter-connections between different factors and the social practices that make up peoples' everyday lives [33].

The structure of this chapter follows this insight. First, we present factors at the individual level, second we discuss the literature on the system-level aspects of food waste, and finally we present a social-practice approach to understanding consumer food waste, focusing on food practices in households.

2.1 Individual factors

Research on consumer behaviour analyses personal determinants of food choices and food-related behaviour. Mainly applied to food consumption from a health perspective and later extended to sustainable consumer behaviour [34–36], this research field aims to understand the influence of personal factors on food waste and food behaviours in general [30–32,37,38]. From this perspective, behaviour affecting consumer food-waste is determined by consumers' **motivation** (attitude, perceptions, problem awareness, norms and attitudes to wasting food), **resources and opportunities** (availability of time and money and of food of the right quality and quantity; access to technologies), and **ability to control and change behaviour** (including habits) through the mobilization of skills, knowledge and resources [30,39]. Other factors, including age and gender, skills (e.g. for cooking) and life experience, complete the set of personal factors [30] (see section 2.2).

The focal entity in behavioural models relating to food is the individual, whose behaviour is determined and can be changed by modifying the relevant personal factors mentioned above. This does not mean that addressing one such factor, e.g. motivation through awareness campaigns, will be sufficient to obtain a change in behaviour; often multiple factors must be simultaneously addressed that cause a positive change in motivation, resources/opportunity and ability [40] (see section 2.4).

Attitudes are a key category affecting consumer behaviour, and include food safety and risk, and healthy eating. Attitudes about the value of food leads to less food waste, whereas concerns about food safety and the wish to eat freshly cooked food instead of leftovers tend to generate more food waste [34,41]. Personal **values** and **identity** and **moral standpoints** regarding waste come into play too, as do individually perceived social **norms** and personal norms. For example, the 'good provider identity', which refers to the wish to be a 'good' parent or a 'good' partner, [42] and the 'good mother identity' [43] are both associated with the generation of food waste.

An important factor in inaction on food waste seems be people's **perceptions** of their own environmental efforts, which does not necessarily reflect the environmental impact of their actual practices [37]. For example, persuading people to compost food waste may give them a sense of already doing something 'good', thus reducing the motivation to reduce the food surplus [37]. Procrastination in acting and **making excuses** for not making an effort to reduce food waste have also been commonly observed, e.g. due to problem denial, externalisation of responsibility (e.g. to government), or feelings of helplessness [37].

Skills and knowledge in respect of food storage, preservation, cooking, date-labels and meal-planning are associated with lower levels of food waste [44,45], as are higher levels of awareness about food waste and its social, environmental and economic implications. Conversely, when considering **education,** individuals with a higher level of education tend to generate more food waste, according to some studies [46], although the reasons for this are not clear. There is also evidence that **employment status** affects food waste: being employed and having a full-time job or a large work load all tend to increase food waste, possibly because it reduces the time or attention invested in household food practices [31,47].

Age is an important factor in respect of food waste according to literature showing that the older you are the less food you waste [31,32,37]. The explanations for this relate to attitudes to frugality and food (e.g. due to experiences of austerity), a greater likelihood of being educated in cooking and food management and having a greater knowledge of the impacts of food waste [31,48].

Through their interplay, various factors shape individuals' *intentions* to reduce food waste. However, *actual* behaviour and measured food-waste levels (as opposed to predicted levels) are influenced by other factors originating in the individual's social and physical context or setting, be it a household, a social gathering, a restaurant, or a shop. Several studies have demonstrated the gap between an individual's intentions and the failures to reduce food waste [34,44] that result from contextual factors. This so-called '**intention–behaviour gap'** [49] shows that it is not enough to consider individual factors in the search for effective strategies enabling consumers to change their behaviour.

2.2 System-level factors

Food waste has economic, social and cultural determinants operating at higher levels in society and the food system, which influence individual consumers' behaviour related to food waste. Food waste-reduction interventions must therefore take account of system-level factors in achieving the desired impact on consumers' decision-making.

2.2.1 ECONOMIC FACTORS

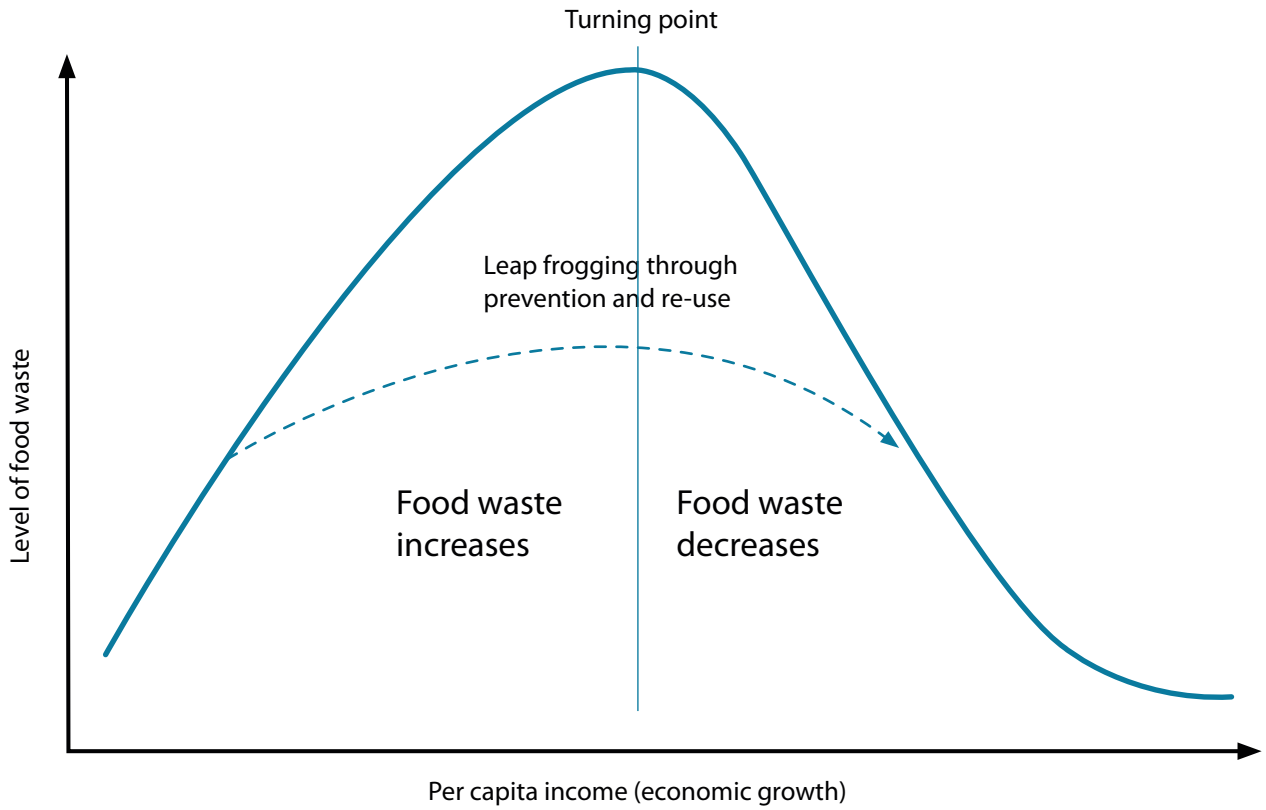
2.2.1.1 INCOME AND LIVING STANDARDS

The causal relationship between income and food waste is one of those areas where research and data show diverging results. High living standards normally mean that households spend a smaller share of their total income on food, which entails the risk that food is perceived to be less valuable (relative to the value of total consumption) and therefore more likely to be wasted [37,50,51]. Thus, in high-income countries such as the US, UK, Canada and Singapore, the share of household income spent on food items is below 10%, whereas in developing countries the share is often above 40%, for example, in Nigeria, Kenya, Cameroon or Kazakhstan [52]. The relative importance of food expenditure in household budgets may also be affected by local food prices, which can differ substantially between areas or countries with similar income levels [53,54], and by culturally determined preferences for food vis-à-vis other consumption goods. In addition to great disparities of income between countries, large within-country variations in food-waste levels are found in emerging economies with a growing population of high- and middle-income households, mainly in urban areas [1].

However, no relationship between income or living standard and food waste can clearly be identified. One recent study [51] found a positive correlation between national income and food waste and concluded that, if growing economies follow the same growth paths as high-income countries, similar food waste patterns will evolve there. Yet other studies found no correlation between income and food waste [31].

The relationship may also follow a so-called environmental Kuznets curve (see Figure 2.1), shaped like an inverted U, whereby food waste increases with income up to a turning point, after which a further increase in affluence enables or incentivises society (or households) to invest more attention and resources in reducing food waste, thus causing waste levels to decline. While such a relationship is difficult to verify empirically due to many confounding factors [55], this report documents that ample opportunity exists for developing countries and cities to 'leapfrog' waste generation through prevention and re-use strategies as their economies grow. The benefit is not only reduced environmental impact but also the avoided cost of investing in expensive recycling and recovery infrastructure (see section 4.3).

Figure 2.1. Environmental Kuznets curve for food waste showing a leapfrogging pathway through prevention and re-use strategies. Source: the authors.



The scientific uncertainty about the effect of income on food waste may be partly resolved by examining changes in social practices (section 2.3) that are associated with household income, but that have a more direct impact on food waste. For example, more full-time employment that puts temporal constraints on the attention given to preventing food waste [31], or improved access to home refrigeration that can conversely reduce food waste.

2.2.1.2 MARKET AND SUPPLY CHAIN FACTORS

The structure and functioning of agro-food systems are important factors influencing food waste by households, as they affect a range of the household food practices (section 2.3), such as meal planning, food shopping and food sharing. These market factors include households' distance to food outlets (local markets, grocery stores, supermarkets, online/delivery shops, farms, fish land sites, kitchen gardens, etc.), as well as the characteristics of food outlets, including physical setting (size, accessibility), product range, packaging, marketing (e.g. buy-two-for one's price) and food waste-reduction policies such as reducing the prices of products close to expiry or Best Before dates. The level of food prices, affected by, for example, the level of competition and the presence of discount stores [32], is also a key factor. Finally, food-sharing arrangements and mobile apps are increasingly part of food markets (see Chapter 3 on technology). These market conditions vary greatly within and between countries and regions of the world, and their specifics should thus be considered when designing consumer-oriented food waste-prevention programmes.

2.2.1.3 ECONOMIC SHOCKS AND COVID-19

Finally, external shocks or emergencies like the current COVID-19 pandemic have a huge impact on the global economy as a whole, as well as on food systems and individual consumers. COVID-19 has transformed peoples' lives and lifestyles because of lock-downs, the stockpiling of essential food, or temporary or permanent income shocks [13]. All of these factors significantly influence food provisioning and consumption patterns and are therefore also likely to impact on the food waste of consumers and households [10,12,38], as well as increasing food insecurity, especially among vulnerable groups, such as people with disabilities and households with children [38].

It is still too early to say what the long-term effects of COVID-19 will be on food waste, but early research shows that people living in high impact areas in Japan have changed their attitudes and initiated behavioural change towards preventing food waste [56]. Another study of Italian food consumers showed an increase in food purchasing due to the fear of food shortages. However, the Italian study showed an actual drop in food wastage due to an increased awareness among the population of the importance of avoiding or at least reducing food waste that has economic and environmental implications for society [11]. Similarly, a recent report from the Waste & Resources Action Programme (WRAP) showed that food waste decreased in the UK by 22% during the first year of the pandemic [12].

2.2.2 SOCIAL FACTORS, INCLUDING GENDER AND HOUSEHOLD COMPOSITION

Gender is an important factor affecting attitudes and practices relating to food acquisition, preparation, consumption and disposal [57]. This is mainly due to the segregation of household responsibilities between men and women. Research shows that women are more likely to be responsible for food-related household responsibilities such as grocery shopping and meal preparation, and are more likely to purchase local food and organic food products [57]. A study from Bosnia and Herzegovina showed that women are more likely to reduce waste and to sort out recyclable waste at home, and they tend to experience more guilt when discarding food and are more likely to plan food purchases to avoid waste [67]. Other studies, however, indicate that gender does not significantly affect food waste or that women waste more food, including in cases where they are responsible for the household's shopping for groceries [31]. Hence, while the effect of gender on food waste seems to vary a lot [31,46], it nevertheless plays a key role in household food practices and should therefore be considered in food-waste reduction interventions (see Box 2.1).

Research has also considered how the broader **demographic composition of households,** regarding age, generation, family structure, size etc., affect food-waste behaviour and outcomes. Hence, one such study observed that, while older generations may be more frugal and knowledgeable regarding food, which tends to reduce food waste, retired people tend to live in small households, which is sometimes related to higher levels of food waste [28]. Several other studies, however, have found that large households produce less food waste per person [31]. A recent survey from the UK also found that households with children wasted relatively more purchased and cooked food, among other factors due to greater on-plate leftovers [38]. Finally, in Turkey, households consisting of young and highly educated people working in full-time jobs and having no children were associated with more careless food planning and cooking behaviour, thus causing high levels food waste [47].

Box 2.1. A gender perspective on food waste

Women and men have different needs, constraints and preferences when carrying out food-related activities. In order to understand food waste from a gender perspective, the different productive and social roles of men and women in the food value chain and how this influences its efficiency must be recognized.

The gender perspective and gender dynamics therefore need to be fully incorporated when assessing the causes and impacts of food waste and designing and implementing responses and interventions. A gender-blind approach to food waste would risk being less effective and even exacerbating gender inequalities along the food value chain.

Research and interventions on consumer food waste should therefore consider the following aspects (adapted from [58], p.14):

- Women's and men's functions in productive (e.g. farming) and reproductive (e.g. child-care) activities
- Women's and men's access to and control over resources, assets and services
- Women's and men's power and agency, and their ability to have a voice and influence decision-making
- Legal frameworks on and cultural and social norms concerning men and women as economic actors

Source: [58]

Photo credit: Shutterstock

2.2.3 CULTURAL FACTORS

There is only limited research on how different cultural attributes affect individual behaviour concerning food waste [59]. Nevertheless, cultural factors seem to play a significant role in patterns of food waste among consumers [30,32,60]. Culture shapes society's social norms and values, which influence individuals' motivations to reduce food waste, as well as their practices of sharing or donating food to avoid waste [59].

Research also shows that significant food waste is generated during religious and social occasions globally, for example, during Ramadan [61], at Christmas [62] and during other festivals [63]. Other research has examined culturally determined factors related to food customs and practices at ceremonies. For example, cultural practices of serving extravagant meals and large numbers of dishes at ceremonies, such as weddings, cause excessive food waste [64].

Ramadan 'Iftar' dishes.
Photo credit: Shutterstock

Another cultural practice with implications for food waste is collaborative consumption that results in over-purchasing, overconsuming and wasting food [65]. Collaborative consumption, i.e. when a group of people contribute to and take from a collective pool of food, is a common social practice (e.g., potluck) in many countries and is widely used at restaurants where groups order many dishes to share. However, because of motives of generosity and cognitive errors in understanding the reciprocal nature of collaborative consumption, such social and cultural practices create excessive amounts of food waste [65].

2.2.3.1 FRUGALITY AND EXTRAVAGANCE

Other studies have illustrated the culturally embedded practices and norms of food waste behaviour by referring to culturally specific idioms that relate to food waste. For example, a study of the Japanese expression *'Mottainai'*, which is used to express regret at throwing something valuable away, has been found to impact on food waste practices in Japan. Another study focussed on the Chinese term *'mianzi'*, which can broadly be translated as status, prestige and social position in society and has been associated with practices of an extravagant dining-out culture resulting in excessive leftovers [66].

Frugality in the kitchen. Photo credit: Shutterstock

Although frugality (i.e., being economical in use or expenditure) and environmental concerns are both related to sustainable consumption patterns, they draw on different sets of values. Frugal consumer behaviour is more often related to income constraints and low levels of materialism, whereas environmental concerns are associated with socially conscious consumption patterns [67]. In other words, behaviour that leaves behind less food waste may build on different sets of values. Such underlying values also tend to differ by age and generation [33]. As a consequence, to promote and activate values that can motivate consumers to reduce food waste, it is necessary to understand the specific values of a given society and how these values are associated with food waste [68].

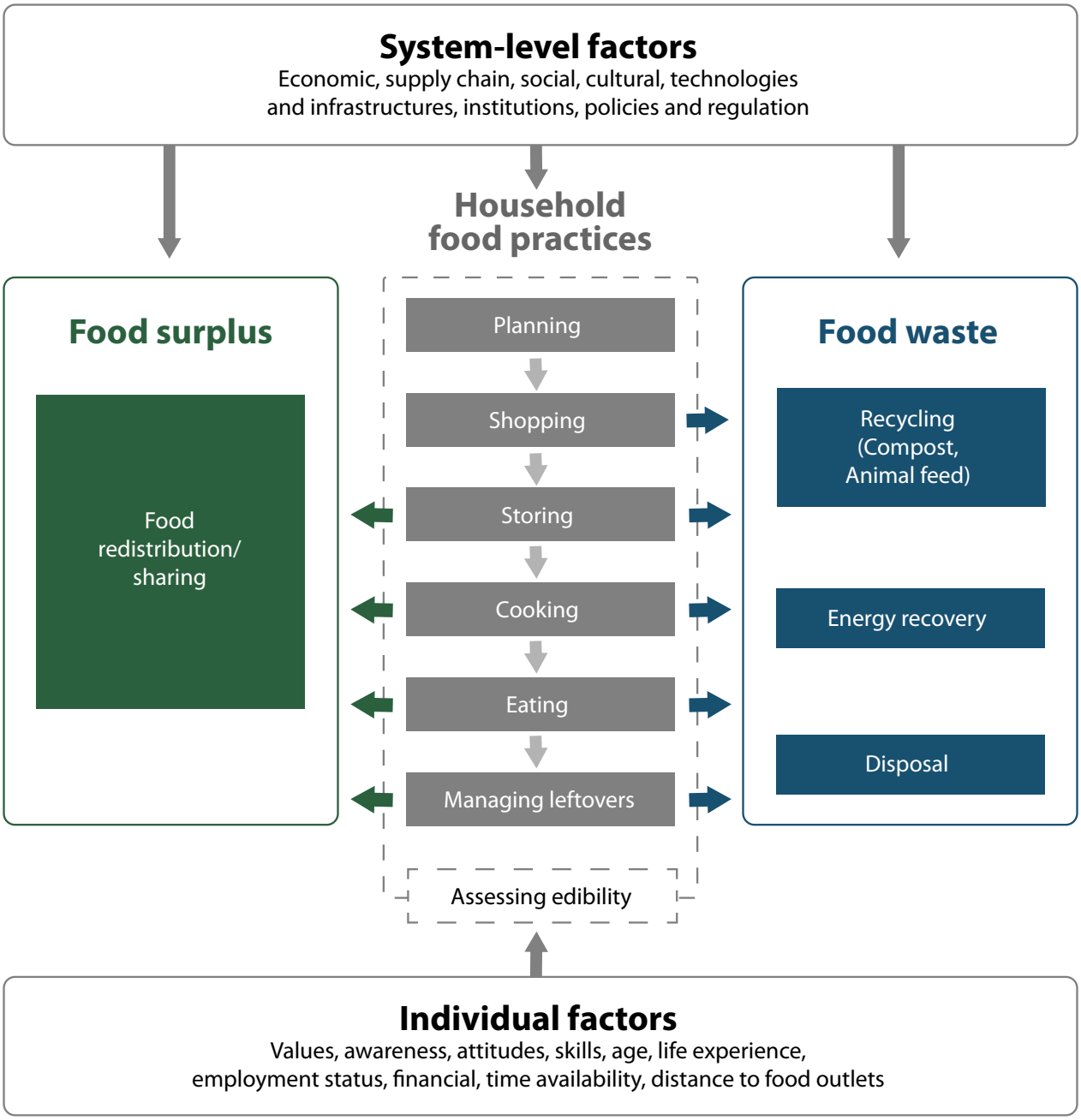
2.3 Food consumption as a social practice

The social and physical settings where food consumption takes place are relevant for understanding food-waste generation by consumers and for designing preventive measures. Social practice theory is a prominent approach to understanding the determinants of 'what people actually do' [69], in particular in the settings of household and family. There is a rich research literature on the social practices of food consumption and food waste [31,69,70]. By focusing on peoples' everyday food practices, we can observe in a real-life setting how individual and system-level factors interact and influence the food-waste behavior of consumers [31]. This opens up new perspectives on food-waste reduction and arguably more effective interventions to achieve it.

Food practices in the domestic sphere of the home, household and family include the activities of food planning, shopping, cooking, eating, managing leftovers and disposal or redistribution [31] – in other words, a food life-cycle. At each stage in the cycle, the consumer assesses the quality and edibility of the food[1]. Figure 2.2 presents a multi-level model to visualize consumers' food-waste behaviour within households. At the centre is the household food practices just mentioned, while each side shows the consequences of the practices in terms of the generation of food surpluses (for redistribution) or food waste (for recycling, energy recovery or disposal). The top and bottom parts illustrate how the food practices are influenced by factors operating at the individual (section 2.1) and system levels (section 2.2). The mechanisms depicted here are considered generic, but the priorities, institutions, capacities etc. can vary among countries and areas (e.g. rural and urban), making different waste outcomes possible.

1 *The food consumption process described here is an idealised version of the real world, in which food practices do not necessarily occur as a carefully planned process, as Figure 2.2 may imply, but are also influenced by possibly less rational impulses, habits and similar behaviour.*

Figure 2.2. Household food practices and the links to food surpluses and food waste.



Household food practices involve a range of activities, from planning and shopping via cooking to managing leftovers, each of which is influenced by system-level and individual factors. Source: adapted from [31,32]

Research also shows that food practices are intertwined with other social practices, e.g., recreation, occupation/work, care work and mobility [71–73]. In France, for example, bulk shopping and cooking were popular in households with highly interlocked practices and where the households have other time-competing practices requiring their attention such as work, children or social events [72]. Food-waste prevention efforts must therefore take account of these other practice areas to be effective.

Moreover, it is often assumed that social food practices are static, but research shows that they can in fact change rapidly with changes in perceptions and knowledge, competences, physical or social circumstances, the family life-cycle, etc. [31,74]. This means that it is feasible to change food consumption in a greener direction, but also that, to be effective, food-waste interventions must be carefully designed to suit the life situation of the target group.

2.4 Understanding consumer food waste at multiple levels

Understanding consumers' food-wasting behaviour is a complex endeavour. Many intertwined factors at multiple levels (individual, household, society) embedded in social practices influence the way food surpluses and food waste are managed at the consumption stage of value chains.

Today we only have limited knowledge about these factors and how they influence food-waste behaviour in different situations (at home, school or at work), not least across different cultures and countries. There is also a lack of gender-disaggregated data on perceptions and behaviour related to food waste. For example, data about who is generally responsible for the management of food purchases and disposal in households could show the patterns and differences in the way gender affects food waste. Such data can then be used to inform policies that are sensitive to these differences and to adapt public awareness campaigns on food waste to the particularities of each gender.

While the interplay between the various factors at multiple levels has not been fully understood, it cannot be ignored either. For example, changing attitudes to food waste by individuals in the direction of valuing food will have only a limited impact on food-waste behaviour if the change is not supported by other household members or if supermarkets continue to encourage over-purchasing. Similarly, the intention-behaviour gap – the gap between an individual's intentions and failures to reduce food waste – also reveal the limitations of, for example, information campaigns. In some contextual settings, the motivation and ability to change behaviour is hindered by the lack of opportunity, for example, by access to refrigerators in developing countries (see section 3.1.1) or time limitations due to full-time employment.

Furthermore, consumer food waste may have part of its origin in decisions in upstream food-processing stages (e.g. through incomprehensible date labels, packaging being too large or not re-sealable, retailer and sales strategies such as bulk packages, special offers, etc.), which are outside the scope of individual action and therefore require non-individual factors to be considered too. These include technology and infrastructure, but also cultural and social norms and values, which are influenced by the specific circumstances for food consumption. For example, group dining (food-based collaborative consumption) often results in over-purchasing, over-consuming and wasting food to a higher degree.

However, as has been seen with other urgent policy areas, the development and diffusion of technologies and initiatives to prevent food waste need to move ahead, even if research does not yet provide a comprehensive understanding of all of these factors. In respect of consumer food-waste behaviour, the opportunities to intervene on a level playing field are nevertheless very wide.

3. GREEN AND DIGITAL TECHNOLOGIES

Technologies are one of the key instruments deployed in food-reduction interventions by governments, cities, businesses, NGOs and other actors, and they are often used in support of other instruments, such as regulation and nudges, as discussed in Chapter 4.

We define food waste-reduction technologies as those that involve the introduction or modification of technologies and/or objects that seek to prevent or re-use surplus food for human consumption (preferable options), or to improve the management of unavoidable food waste through recycling, energy recovery or engineered landfill (less preferred options) [25].

Food waste-reduction technologies include both green technologies and digital technologies (defined in section 1.5). They range from simple devices such as fridges and shopping apps via integrated supply-chain infrastructure such as cold chains to advanced food preservation, packaging and information technologies. A large number of digital technologies and tools have been developed in recent years that address food-waste reductions by consumers. An inventory of ICT tools and smart technologies related to food waste was created in 2016-17 and includes 77 such tools or technologies [75], although many more are likely to have been developed since. They cover a range of consumer-facing mobile apps, as well as intelligent devices using sensors, such as the smart fridge and smart bin.

This chapter emphasises the technologies that primarily address food waste at the consumption stage while recognising that optimizing food-waste reduction requires a system-level perspective that integrates technological and management options along the entire value chain (including end-of-life activities). It also focuses on technologies that address the (preferable) options of the prevention of food surpluses or their re-use for human consumption. Figure 3.1 provides an overview of these technologies by type (green, digital, IoT, and combinations thereof) and function, including a short description. Technologies deployed to manage unavoidable food waste are addressed as part of the discussion of food-waste reduction initiatives in Chapter 4 (section 4.4).

Figure 3.1. Technologies addressing the prevention and re-use of food surpluses.

PREVENTION

Type	Function	Description
Green	Thermal preservation	*Refrigeration and cold chains*
	Biological and bio-chemical preservation	*Use of essential oils and natural extracts in active packaging*
Green + Digital	Smartphone apps: Food planning, shopping, storage & cooking	*Guide, track and inform consumers in food related choices to reduce food waste*
Green + Digital + IoT	Smart packaging	*Use of sensors and data carriers to monitor food quality*
	Smart labelling	*Use of data embedded barcodes (DEB) to improve information about food quality*
	Smart storage and disposal	*Wifi connected fridges and bins equiped with cameras and sensors to monitor food quality and food quantity*

RE-USE

Type	Function	Description
Green + Digital	Smartphone apps: Food sharing and redistribution	*Different types of food sharing apps: Sharing for money, sharing for charity or sharing for the community*

All the technologies discussed in this chapter are listed, including type, main function, and description.

In the remainder of the chapter, we first discuss technologies that enable the preservation of food along the supply chain, including thermal, biological and chemical technologies. We then discuss recent developments in 'smart' packaging, labelling and storage technologies that provide enhanced information about the quality and freshness of food along the supply chain, or about food storage or disposal in the household. We finally zoom in on the plethora of smartphone apps that have been developed in recent years to address food-waste prevention and re-use.

3.1 Food-preservation technologies along the supply chain

Fresh-food transport and distribution is often very inefficient and causes substantial food waste, as well as food-borne illnesses. These problems can be addressed by combining smart sensing and communication technologies with enhanced quality control and logistical operations along the supply chain [76]. In the context of this report, it is important to note that food-preservation technologies and practices along the supply chain can also prevent food waste at the consumption stage [76,77].

While food preservation has always been an integral part of food systems, driven by concerns for economy, food safety and food security, a focus on food-waste prevention provides an additional incentive for innovating and applying food-preservation technologies. Several factors can lead to food becoming unsafe and hence wasted, such as naturally occurring toxins in food itself, microorganisms, contaminated water and pesticide residues, as well as poor and unhygienic handling and storage conditions and a lack of adequate temperature control [77]. Here we summarise key technologies and innovations in thermal, biological and bio-chemical food preservation along the food supply chain that can help prevent food waste at the consumption stage.

3.1.1 THERMAL PRESERVATION (REFRIGERATION, COLD CHAINS)

A cold chain is a supply chain that uses refrigeration to improve food preservation [78]: for perishable foods, an optimized cold chain plays a critical role in food-waste prevention [78]. Broken cold chains are responsible for a large part of the world's food waste. Especially in developing countries, cold chains are largely missing or broken along long sections of the supply chain, leading to substantial food and economic losses along its length [78]. In China, for example, 85% of perishable food is transported in trucks without refrigeration, compared to only 10% in the US [78,79]. These challenges apply also to the final stages of food distribution and consumption, where research suggests that large food-waste savings can be made through simple and low-cost technologies and practices. This research was recently reviewed by [78], on which the insights below mainly draw.

Cold chain infrastructure. Photo credit: Shutterstock

Studies of consumers' transport of perishable foods from retailer to household show that the temperatures often rise significantly above the levels recommended to maintain food quality and food safety. Transport times can also be long, varying between 40 and 75 minutes in some studies. For example, one study reviewed by [78] found that the temperature of meat and yoghurt during transportation by consumers rose to above 6^{0}C, while in another the average temperature of meat products during transportation reached 9.8^{0}C. Against this background, a simple recommended measure to avoid food spoilage due to consumer transport is to 'protect perishable food products using insulated bags or containers when the ambient temperature is warm or the delay between retail and storage … is significant' [78].

Box 3.1. Sustainable cold chains and the Kigali Amendment

About 14 per cent of food spoils before it reaches retailers according to the FAO. Expanding cold chains reduce food loss by keeping it fresh post-harvest and in transit. But it will come with a climate price tag if we are not careful. This is because many current cold-chain systems use refrigerants with high global-warming potentials and electricity derived from fossil fuels. To expand sustainably, we must lean into international processes such as the Kigali Amendment to the Montreal Protocol. The Kigali Amendment provides an opportunity to redesign cooling equipment to be more energy-efficient.

Food is normally stored for some time in the household before it is consumed, and here too temperature control is especially important. In high-income countries, studies have shown that the temperature inside the majority of refrigerators is too high [78], averaging between 6^{0}C and 7^{0}C, whereas the recommended fridge temperature is generally below 5^{0}C [80]. The effects on product shelf lives of these deviations in temperature can be significant. Thus, a study of the United Kingdom estimated that maintaining refrigerators at a temperature of 4^{0}C (instead of an assumed 7^{0}C) would save an estimated 71,000 tons, or £162.9 million, of food annually [81]. In comparison, total household food waste in the UK is estimated at 4.5 million tonnes in 2018 [82]. In this context, modern fridges with advanced temperature and humidity controls, including dedicated compartments for food types with different optimal storage conditions, can extend the shelf life of food (also beyond the Best Before dates) at the consumption stage of supply chains, thereby reducing food waste. An example is the BioFresh technology by the household appliance producer Liebherr [83].

Box 3.2. High-end innovative household storage

The *vacuvita* household vacuum storage system increases shelf-life by protecting food from oxygen and moisture and includes an app that helps obtain an overview of the stored food and its remaining shelf life [75,84]. The technology is deemed less relevant for most households in low- and middle-income countries due to the price.

3.1.1.1 COLD CHAINS IN DEVELOPING REGIONS

In low- and middle-income countries, however, many consumers do not have access to a refrigerator, making temperature control as a measure against food waste very challenging. For example, in rural China, 77.6% of households have access to a refrigerator and in South Africa the figure is 68.4%, while in Indonesia 55.5% of urban households own a fridge, against only 24.7% in rural areas [78]. The major reasons for the non-ownership of a refrigerator in these regions are the high capital cost and intermittent electricity supplies [78], while in some cases consumer trust in active refrigeration is low due to the poor design of units and bad management [85]. Off-grid small-scale refrigeration technologies have been developed to compensate for the absence or unreliability of power, assessed by [85]. They include mechanical compression fridges powered by either mini- or micro-grid (low-cost AC components) or solar PV modules (high/medium-cost DC components) (see photo below), fridges using an LPG or kerosene burner, thermoelectric coolers, vapour-compression solar refrigeration, and sorption refrigerators driven by solar thermal energy, waste heat or traditional fuels. The latter type, powered by solar heat, is deemed a feasible and cost-effective off-grid solution where solar radiation is widely available, although there are still few commercial products on the market [85]. Community refrigerators using off-grid technologies have also been implemented and can reduce costs per household [85]. In general, off-grid refrigeration technologies can reduce the spoilage of refrigerated food due to power cuts in the main grid, which is a common occurrence in developing countries.

Experimenting with a solar PV-powered vapour-compression refrigerator in Nigeria. Photo credit: [86]

Cold-chain technologies further upstream in the supply chain that are adapted to local conditions also show promise. In Kampala, Uganda, for example, the Fruiti-Cycle company has designed an electric tricycle with a refrigerated storage unit, which uses an evaporative cooling system that is solar powered, to prolong the shelf life of fresh produce during distribution. The storage unit is detachable and can be used in the local market by vendors to preserve their produce for up to five days [87].

The Fruiti-Cycle. Photo credit: Fruiti-Cycle

Developing cold chains in developing countries in the context of climate action will require improved access to affordable and reliable renewable energy resources, such as wind and solar power.

3.1.2 BIOLOGICAL AND BIO-CHEMICAL PRESERVATION

Food industries apply a wide range of biological and chemical preservation technologies to keep their food products attractive, fresh and safe [77]. It is beyond the scope of this report to provide a comprehensive review of these technologies; instead we present here selected innovations in food packaging that integrate biological with chemical techniques.

Food packaging protects food from external factors, such as temperature, light and humidity, that can lead to their degradation, as well as from other environmental influences such as odours, microorganisms, dust, and vibrations [88]. As such, the development and diffusion of new packaging technologies is essential for preventing food waste [89]. Packaging containing modified atmospheres, where especially CO_2 is used as a microbial agent, and CO_2 and N_2 as antioxidants, is a well-established technology that is seeing a widespread adoption. Box 3.3 shows how a modified atmosphere is used to enhance the shelf-life of grains in Uganda.

Box. 3.3. Air-tight grain packaging in Uganda

In Uganda, air-tight double-layer bags have been introduced to enhance grain storage. They consist of a gas-proof inner bag placed inside a tougher open weave polypropylene bag for protection against physical damage. After filling, they are tightly closed with a string. Because the bags are hermetically closed, some weeks after being filled with grain, a modified atmosphere is created that will kill any pests. This technology has extended the shelf-life of grain to 2-3 seasons or 1.5 years. The bags have a capacity of either 50 or 100kg, and at least two brands are available on the market. Source: [90]

In response to increasing consumer demand for less artificial ingredients, companies are looking for more natural means to keep food fresh and safe. Box 3.4 presents an example of a recent innovation in fermentation-enabled bioprotection technology that is explicitly linked to food-waste prevention.

Box 3.4. Bioprotection: increasing shelf-life and freshness the natural way

In a food-processing context, bioprotection refers to the use of natural microbial food cultures in the fermentation process. Improved fermentation with better food cultures supports the inhibition of unwanted contaminants, helping delay spoilage and enhancing food safety in a natural way [91]. The food-ingredients company Chr. Hansen has developed a culture that can help protect dairy products such as yoghurt against spoilage caused by naturally occurring yeast and mould, thus increasing the shelf-life and reducing waste at the consumption, retail and manufacturing stages [92]. As the technique also works under sub-optimal cold-chain and production conditions, it appears suitable for dairy industries in low- and middle-income countries as well.

Photo credit: Chr. Hansen

3.1.2.1 ACTIVE PACKAGING

A recent technological innovation in food preservation is active packaging (AP) [89]. AP is 'a system that interacts between food and packaging either by direct contact or by migration of compounds to the headspace' [89]. AP extends the shelf life and freshness of food products through the regulation of aspects responsible for food degradation, such as physiological (e.g., respiration of fresh fruit), chemical (e.g., lipid oxidation), physical (e.g., dehydration) and microbiological processes. AP technologies have been applied to foods such as fruit, vegetables, fish, meat and bakery products [89]. Materials that release active substances to preserve food are particularly important in AP, and these often involve the use of films of polymeric materials to act as carriers for different active compounds [89].

Concerns about using synthetic additives in food have incentivised the use of natural products in AP, especially essential oils obtained from plant materials [88], as well as various natural extracts [89]. An example is the Apeel technology [93] recently introduced by retailers in Denmark, Germany and the US (see Box 3.5).

AP technologies seem mainly relevant for the more affluent consumer segments in low- and middle-income countries, who are more likely to purchase packaged or treated food products from 'industrial' supply chains. However, as the size of this segment is increasing fast, AP technologies should nevertheless have the attention of food-system actors and policy-makers in these countries.

Box 3.5. Extending the shelf-life of fresh produce through coating

The Apeel technology [93] is a coating applied to the skin of fruits and vegetables such as oranges and avocados to extend their freshness and durability [94]. Apeel is made from waste pulp, peels and seeds from vegetables and fruits and 'forms a coating over the fruit or vegetable's peel, which slows down the ripening process by allowing less water to evaporate from the inside and less oxygen to penetrate from the outside' [95]. According to the producer, the shelf life of fresh produce treated with Apeel is at least double that of untreated produce [93].

Photo credit: Shutterstock

3.2 Smart packaging, labelling and storage technologies

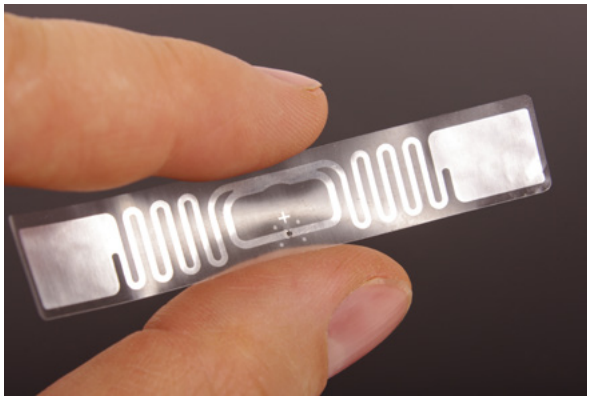
3.2.1 SMART PACKAGING

Smart or intelligent packaging (IP) are systems that can monitor the quality status of a product permanently by providing information about events inside or outside the packaging environment and sharing the information with supply-chain actors, including retailers and consumers [89,96]. IP technologies include indicators (e.g. time temperature, gas, pH, colour), sensors (gas sensors detecting changes in CO_2 or H_2S due to biological reactions inside the packaging, or biosensors detecting e.g. pathogens), and data carriers (e.g. barcode and QR-code labels and radio frequency identification tags) to monitor, trace and communicate food quality [89,96]. Hence, while not designed to extend the shelf life of food products, IP can avoid unnecessary food waste by providing more accurate and objective information to the consumer and distributor about the actual quality status of food products than relying only on standard 'Best Before' dates or subjective assessments of the product's visual or physical appearance. This can have a real effect on prevention, as the expiry dates of food products have a significant safety margin, which tends to be quality-related rather than safety-related [97], e.g. typically 20% to 30% for fresh meat [98].

IP systems are not yet widespread in the market according to [96], due to the costs but also to a lack of awareness of their benefits among manufacturers and retailers. Consumer confidence in the safety of IP systems also needs to be built. Given such challenges, for some time at least their contribution to food-waste prevention is likely to be confined to high-value fresh produce such as meat, fish and ready-to-eat convenience foods (e.g. salads) in high- and middle-income countries.

3.2.2 SMART LABELLING

Smart food-labelling can reduce food loss at or near the consumption stage by providing retailers, food-service companies and/or consumers with easy access to enhanced information on food quality, handling and use – including shelf life, storage instructions, freshness, recipes, allergens and information on origin and sustainability – by scanning the label with a smartphone [98]. The data-embedded barcode (DEB or 2D) is a new type of barcode that can be used to convey such information [99] and which is replacing the conventional 1D barcode in many places. Information stored in the DEB can be used to reduce food waste for retailers and food-service companies, partly through 'smarter rotation of stock in store, ensuring shortest life product is sold first, smarter management of price reductions to sell expiring product efficiently, prevention of out of date product being sold at the checkout, and smarter forecasting of demand to drive more efficient ordering to re-stock the store' [99].



Radio-frequency identification (RFID) transponder that can be incorporated in the smart label. According to [100], 'an RFID system consists of a tiny radio transponder, a radio receiver and transmitter. When triggered by an electromagnetic pulse from a nearby RFID reader device, the tag transmits digital data, usually an identifying inventory number, back to the reader. This number can be used to track inventory goods.' Photo credit: Shutterstock

Active links between intelligent packaging (see above) and product labels can be created, through which the quality and freshness of the food is monitored in real-time and communicated to the consumer via the label using an analogue channel (using e.g. a colour code), or digitally to a smartphone app via connected sensors [101]. Box 3.6 provides an example of the innovations that occur with this type of technology.

Box 3.6. Gas sensors indicate freshness on meat packaging labels

The Swedish start-up Innoscentia, in partnership with Canadian Ynvisible, has developed a prototype of their dynamic shelf life-labelling technology that measures gases (volatile organic compounds) inside packaged meat to indicate freshness. The gases are detected by sensors in a label that can connect via a RFID-/NFC signal with the consumer's smartphone [101,102]. They are also developing an analogue dynamic shelf-life label to communicate the status through a colour shift that can be read intuitively both in store and at home.

Photo credit: Innoscentia

Another application of smart labelling technology is dynamic pricing, where digital price tags placed on retailers' shelves enable the automatic discounting of fresh produce based on how close it gets to the expiry date, thereby incentivizing customers to buy soon-to-expire products. An example is the AI-enabled dynamic pricing engine developed by the company Wasteless, which aims to help supermarkets and online grocery stores manage their inventories of perishable products while reducing food waste [103]. While such schemes can reduce food waste by retailers [104,105], they might increase it in households, as the proportion of shelf life in the household is reduced.

Dynamic pricing of perishable products. Photo credit: Wasteless

Smart monitoring and labelling technologies have also been developed in relation to the problem of broken cold chains discussed in section 3.1.1. For example, in the United Kingdom the company Timestrip has developed temperature-indicator labels to be placed on or inside packaging (e.g. containing fresh fruit or seafood) that reveal the length of time a product has been above a predefined temperature threshold during transport and storage. This enables the tracking of temperature breaches, helping to ensure effective cold-chain management along the supply chains [106], ultimately reducing food waste and improving food safety. Another recent innovation is an electronic indicator enabling an electronic record of temperature breaches to be downloaded through a smartphone app [107].

Temperature indicator embedded in food packaging label. Photo credit: Timestrip

3.2.3 SMART LOGISTICS

Pilot studies of so-called intelligent distribution [76] that incorporates the kinds of advanced packaging, monitoring, communication and labelling technologies described above show significant waste-reduction effects on fresh produce, e.g. from 17% to 4% for fresh pork, 15% to 5% for fresh fish, and 37% to 23% for strawberries [76].

3.2.4 SMART STORAGE AND DISPOSAL (INTERNET OF THINGS)

Digital tools using Internet of Things (IoT) technologies (sensors, WiFi, etc.) to improve the storage and disposal of food through enhanced information provision are emerging in the form of prototypes or final products. Two such technologies are the smart fridge and the smart bin.

3.2.4.1 SMART FRIDGE

Standalone fridge cameras can be fitted in regular fridges and be programmed to send images to a smartphone through an internet connection. This allows the consumer to know what is stored in the fridge even when away from home, enabling better planning of food shopping. The app can also be used to track Best Before dates and create a shopping list with the aim of avoiding food waste. Using object-recognition technology in combination with fridge cameras enables an inventory to be automatically maintained of the fridge contents, which can be used to recommend recipes based on the food available, warn the user of food on the verge of completion, and planning of food shopping [108]. That said, user reviews and expert ratings of standalone fridge cams suggest that this technology still needs significant improvements to achieve widespread acceptance.

The smart fridge integrates the cameras and internet connection in its original design and typically also has a screen on its front displaying the content of the fridge (see picture). The WiFi-connected smart fridge studied by [109] allowed the user to order groceries through the screen on the fridge door, to track the use-by dates of products placed inside the fridge, to view the contents of the fridge both from the closed fridge door and remotely using the accompanying smartphone app, and even use the screen for entertainment purposes [110]. In comparison with a regular fridge, the study found that the smart fridge would have environmental benefits in terms of reduced global warming if at least 30% of the use-by dates of the products placed inside the fridge were tracked as a result of the smart fridge technology. While the smart fridge enabled savings in GHGs due to less food waste, less transport for grocery shopping and, but to a lesser extent, fewer door openings, its Internet connection and app resulted in higher energy use compared to a regular fridge [109]. Additional features have been proposed to enhance smart fridges, including weight sensors (enabling the incremental consumption of foodstuffs to be tracked) and voice interfaces (enabling easy registration of information by the user) [111,112].

Smart fridge and smartphone app. Photo credit: Shutterstock

3.2.4.2 SMART BIN

Studies comparing self-reported and measured food waste reveal that consumers consistently underestimate their food waste [113–116]. Here the so-called smart bin and bin cameras could play a role by providing consumers with more accurate information about the types and quantities of their food waste. Smart bins have been developed for commercial kitchens to collect and analyse food-waste data with the aim of reducing waste and saving money. The bins and backend system collect data on waste by means of scales and cameras. The cameras monitor the waste thrown into the bin, and through image or object recognition combined with machine learning, the wasted food items are recognised and automatically recorded in a data platform (and displayed on a table or smartphone), together with the waste amounts recorded by the scales. The analysed data can be used to reduce food waste by kitchen staff and managers. Simpler versions just record the amount of waste using a scale connected to a data platform. Several firms offer smart bin solutions to the hospitality and food-service sector. These include the UK-based Winnow Solutions, which has global coverage, and the Swiss start-up KITRO operating in Switzerland [117–119].[2] Presently, smart bins for food-waste monitoring in private homes are not commercially available, but this could change as the technology matures and costs are brought down.[3]

3.3 Smartphone apps enabling food-waste prevention in households

As noted in section 2.1, food-waste behaviour is influenced by consumers' motivations, resources and opportunities, and the ability to control and change behaviour. Mobile apps have been developed to guide such behaviour in a more sustainable direction, covering the phases of food planning, food acquisition and food storage.

In their study of selected food-waste consumer apps, Vogels et al. [75] found that the provision of incentives for positive behaviour and added value in everyday life were success factors for such apps, but also that the interviewed consumers often lacked an intrinsic motivation to use the apps, feeling that the costs (in terms of time, energy and perseverance) outweighed the benefits. A key factor here was that the consumers interviewed did not consider that they wasted much food. The latter perception is aligned with other studies observing that consumers consistently underestimate their food waste [113–116].

It has also been observed that many of the consumer apps available in the app stores have been created by 'tech-savvy individuals' and suffer from 'limited functionality, infrequent updates, incomplete information from unknown sources, and suboptimal usability' [75]. An important exception is apps built by or for commercial firms, such as supermarket apps and food-sharing apps, which have a wider functionality, are better maintained and have many more installs [75] (see below).

The apps found in the market today that may enhance food-waste prevention cover reminder and food storage apps, and apps that in different ways integrate food planning, shopping, storage and recipes, discussed below.

3.3.1 REMINDER AND FOOD-STORAGE APPS

Reminder and food storage apps are used to remind consumers of the expiry date of a product and/or help keep track of food stored in the home [75]. Vogels et al. [75] list 13 such apps; some identify the product from a list, others based on a scan of the barcode by the user. An example of the latter, for which documentation exists, is the FoodTrek app that alerts consumers of the end dates of food items in their home [120] (see Box 3.7).

2 *A pilot trial of the Winnow smart bin among UK households resulted in a 22% reduction in food waste on average, from 16.6 kg to 13.3 kg, with 83% of the respondents reducing waste [238].*

3 *Smart bins for sorting and managing recyclable waste using AI-based object recognition have been developed for larger buildings, but the technology does not cover food waste [239].*

Box 3.7. Alerting consumers of expiry/Best Before dates

The FoodTrek App is a prototype mobile app that alerts consumers of the end dates of food items in their home [120]. Using a smartphone camera, the app allows the user to scan first the product name and then the 'expiry' or Best Before date, and then stores this information in the phone's calendar. As current legislation does not require this information to be in the same place or in single code, each piece of information must be scanned individually. The user will then be notified about the expiry/Best Before date three days in advance, and again every day up to the day of expiry/Best Before. Additional features include weight and price information, allowing spending and the cost of food waste to be tracked. In a four-week pilot test with 30 participants, there was a 10% decrease in food waste across all food products, and 'participants agreed that getting reminders before the food went out of date was instrumental in them using food products before the end date' [120]. Three quarters of the participants found the app easy to use. However, some participants were not able to make use of the information provided by the app. This included especially households with multiple members, where members had different opinions about when to discard food (in relation to Best Before/expiry dates) and about meal preferences vs. food waste prevention. In a few cases, the alerts increased the users' pre-existing anxieties about exceeding expiry date, causing them to discard the food earlier than before.

Similarly, software developers in Bulgaria have released a mobile app called *CozZo*, which like FoodTrek strives to fight food waste by allowing consumers to manage their food inventory and track expiry dates in due time. The app had at least 15,000 users in Asia, Europe and North America in 2018 [121].

Photo credit: CozZo App

MyKura in Japan is another reminder/storage app that, given its 50,000+ downloads, seems to be widely used [122]. Finally, the *Expired food tracking system* conceptualised by [123] helps users group similar food types together in a fridge, keep track of food expiration dates and send an automatic notification to the user before the purchased food expires or when the quantity of the product is low. It can also generate an automated personalized shopping list based on this information. As the app is at a very early stage of development, its usefulness could not be assessed.

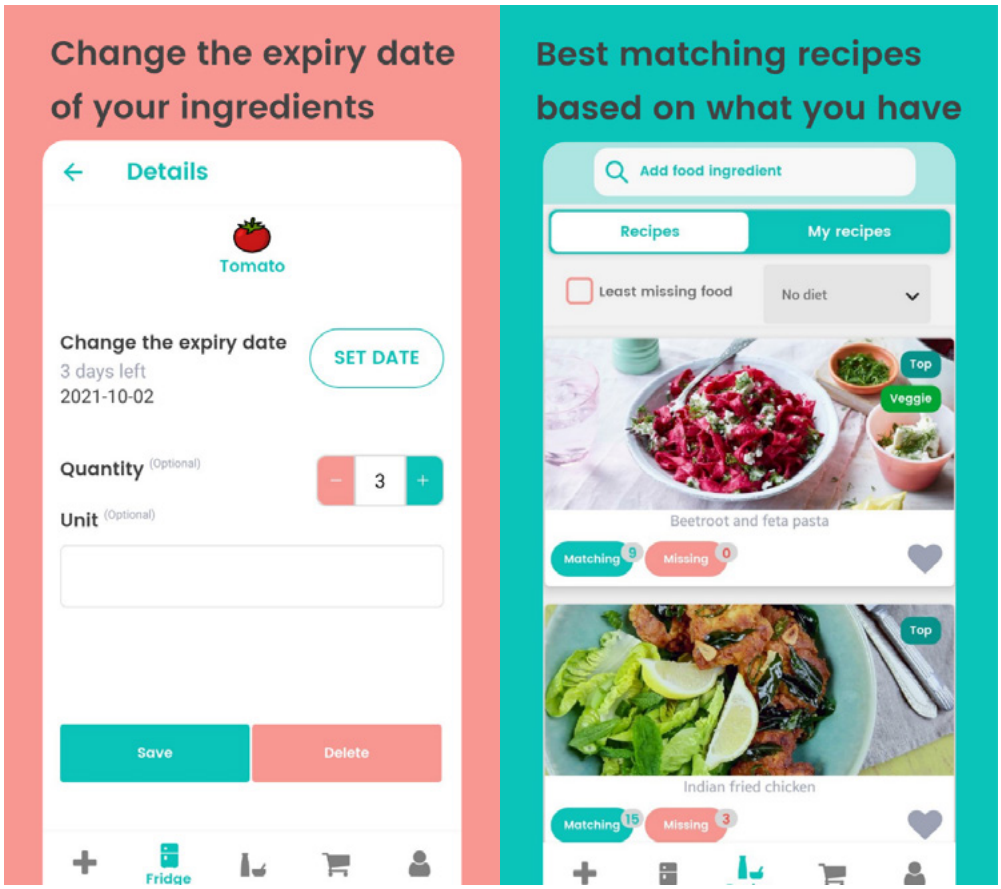
A weakness of many reminder apps is the lack of product databases and/or information links to producers and retailers (e.g. through data-embedded barcodes), so that the origin and history, including the source of the remaining shelf life [75], of the product are unknown. The user must also often add the information manually, which severely limits user friendliness. Independent test or reviews of these apps are very rare.

3.3.2 INTEGRATED CONSUMER APPS (FOOD PLANNING, SHOPPING, STORAGE, RECIPES)

Integrated food planning, shopping and recipe apps [75] have emerged in recent years that provide consumers with comprehensive information, which they can use to reduce the amount of leftover or spoiled food in the household, thereby reducing food waste. These apps often also provide information on the nutrition and sometimes the carbon footprint of food products, thus enabling healthier and more sustainable diets.

The most frequently downloaded apps in this category are the 'supermarket apps' [75] provided by large retail companies, such as the Albert Heijn app (shopping list based on recipes, recipes, special offers) by the Dutch retailer of the same name [124], and the OptUP app (focused on nutrition) by the US supermarket company Kroger [125], although few if any of these apps are designed with food-waste reduction as their main objective.

Numerous integrated apps have been created by independent developers and often have a stronger focus on food waste and other sustainability dimensions than the retailer-created apps. Examples are Evocco (Ireland; carbon footprint of shopping with offset option) [126], AnyList (US; shopping lists, meal plans, recipes) [127], Magic Fridge (France; recipes based on what is available in the fridge, nutritional value of recipes, shopping lists) [128], Empty the Fridge (Belgium; recipes and tips on how to use leftover food) [129], and NoWaste (Denmark; tracking of stored food, meal plans, shopping lists) [130,131]. Again, independent tests or reviews of these apps are very rare.



User interface of the Empty My Fridge smartphone app, which inspires consumers to cook food based on what they have in store and helps them keep track of their stored food. Photo credit: Empty My Fridge

3.4 Smartphone apps enabling food-sharing and redistribution (re-use)

A variety of food-sharing apps and web platforms exist, which support the numerous food-sharing or food-redistribution arrangements that have emerged in recent decades [75,132] to increase the re-use of surplus food from households, restaurants, retail etc. These arrangements can be seen as an extension of the food banks that have existed for a long time in North America, i.e. charitable organizations that collect food that would otherwise go to waste from retailers, manufacturers, farmers, consumers and other sources and redistribute it to the needy for free [132]. Three types of food-sharing models were identified by [132], and for each one we note examples of apps or platforms identified by [75] and other sources [133–136]:

- *Sharing for money* is a business to consumer (B2C) for-profit model intended to reduce waste while also generating revenue. This model mainly prevents food waste at the retail level. One of the largest is Too Good To Go [137] covering several European countries, through which consumers can order and collect food or meals at restaurants, bakeries etc. that would otherwise go to waste. Another example are apps mediating consumers' access to 'sub-standard' food, e.g. Imperfect Foods in the US [138], while the NoFoodWasted app in the Netherlands [139] alerts supermarket shoppers of items that are approaching their expiry date.
- In the *sharing for charity* or 'food bank' model, food is collected from a variety of sources, including consumers, and given to non-profit organizations for redistribution. An example is the social enterprise FoodCloud in Ireland [140], whose retail solution app/platform connects retailers that have surplus food with local charities. In India, the No Food Waste charity organisation collects surplus untouched food from weddings, parties and other food sources to feed the hungry, thus preventing food waste by consumers as well as hunger. A physical variant of the *sharing for charity* model is the social supermarket, where free food, much of it destined for waste, is collected from retailers and manufacturers and sold at discounted prices to the financially poor. Chapter 5 provides further examples of digital technology-enabled food-redistribution schemes in the cities of Bangkok, Belgrade and Bogotá.
- The *sharing for the community* model is a consumer-to-consumer (C2C) or peer-to-peer (P2P) model in which food is shared among consumers [141]. Several such apps are available (see, e.g. [132]), some focusing only on C2C sharing, while others include C2C among other forms of exchange. Box 3.8 provides an example of one of the most widely used apps of the second type, the OLIO food-sharing platform.

Too Good To Go connects consumers with retailers and restaurants that have surplus food. Photo credit: Too Good To Go

Box 3.8. The OLIO C2C and B2C food-sharing platform

One popular food-sharing app is the OLIO P2P food-sharing platform, which connects neighbours with each other and with local businesses to share surplus edible food, such as 'food nearing its sell-by date in local stores, spare home-grown vegetables, bread, or the groceries in your fridge when you go away' [142]. The app originates in the UK, is available in English and Spanish, and is currently used in 59 countries.

In one of the rare impact studies of consumer-focused food-waste apps, [141] analysed the types, weights and retail value of foods offered and shared through OLIO during 19 months in 2017-2018, quantified the associated environmental impacts, and investigated the socioeconomic characteristics of the platform's user network [141]. They found that 60% of the 170,000 listings of food was collected, amounting to about 91 tons of food with a retail value of £720-750,000 that was diverted from food waste and passed on to secondary consumers.

Depending on assumptions about how the food was transported, these food exchanges resulted in GHG emissions savings of 87-156 tons of CO2eq (cradle-to-grave emissions of food waste), and five times higher if considering the carbon opportunity cost of avoided food production (indirect land use change).[4]

The dominant food category listed and collected was bakery goods, while dairy and protein were among the least exchanged. It was also revealed that 71% of the food was listed by volunteers who had collected it from local businesses, and that the collection rate of the food listed by these volunteers was higher (66%) than for food listed by individual households (47%). In other words, direct C2C exchanges made up a small share of the volume of shared food, and 53% of the food offered by consumers was not collected.

Photo credit: OLIO

4 *A recent update of these impact statistics shows 83% of food successfully shared, 83% and 75% of food listings from businesses and households respectively shared, and 1950 tons of CO_2eq avoided per month (personal communication, Sam Macgregor, OLIO).*

3.5 Technology as an accelerator of food-waste reduction initiatives

Technological development in biotechnology has led to new biological and bio-chemical preservation technologies, which are equally important for extending the shelf life of products and ultimately reducing food waste.

Moreover, over the last couple of decades, technological progress within digitalization, sensors and IoT has opened up new technological solutions to handle perishable food especially. This development brings about breakthrough technologies that come with hopes for future projections of food waste. Now or in the future, smart packaging, labelling and storage etc. will enable businesses along the food supply chain to improve their handling, distribution and transportation of food products.

Digital tools combining mobile apps with data platforms seem particularly effective in addressing food surpluses through B2C and C2C food-sharing schemes. Effective food-waste measurement and management systems have also been developed for the food service industry, using smart sensors and scales linked to data analysis and visualisation systems. In contrast, household uptake of 'smart kitchen' technologies such as the smart bin and the smart fridge, as well as mobile apps (reminder, storage, shopping, recipe, etc.), remain low, and their effects on food waste are largely unknown.

Agility is needed when developing technologies to reduce food waste due to the dynamic nature of food markets and supply chains, not least regarding technology. For example, the COVID-19 pandemic has triggered the proliferation of box schemes and food-delivery services using mobile applications. This may cause lasting changes in food shopping, cooking and storage practices, in turn affecting consumer incentives and opportunities in relation to food waste. Apps that address diets, weight watching and allergens are also becoming increasingly popular, possibly changing households' food practices with knock-on effects on food waste.

Men's and women's food-related preferences, priorities and abilities converge in some respects but diverge in others because of the influence of different factors [58]. Hence gender as a factor needs to be considered in the development, application and evaluation of new technologies. This will help ensure that technological innovations do not reinforce gender inequality or food injustice, and it will make technology more effective in enabling and accelerating food-waste reduction initiatives.

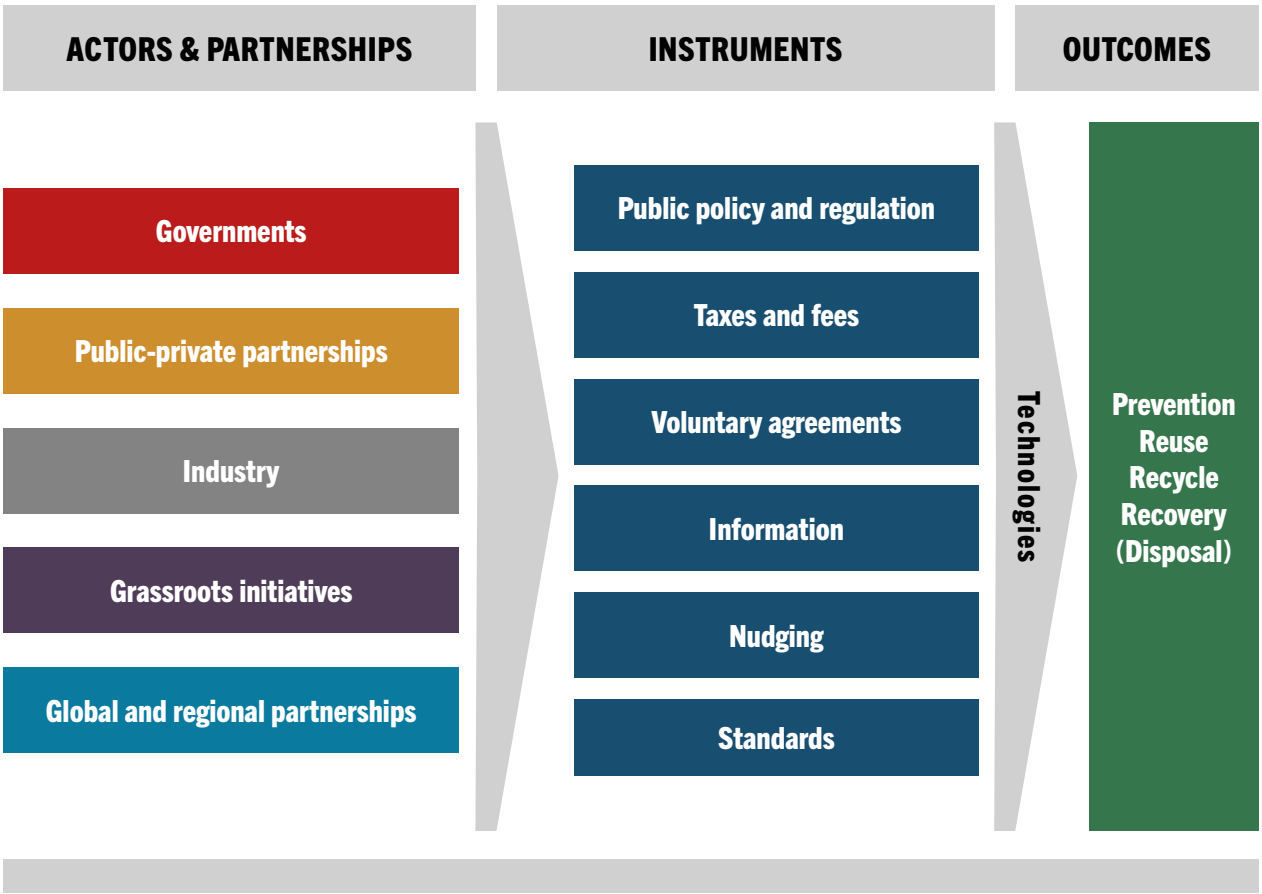
Many of the green and digital technologies reviewed in this chapter have been developed in the context of industrialised food systems and supply chains, which are most common in high-income countries and large cities. In this regard, it is important to emphasize that the diffusion of technological innovations to reduce food waste requires consideration of the enabling environment needed for technologies to be relevant and to work, for example regarding regulations, institutions, infrastructure, markets and complementary technologies. This also applies to the scaling up of technology-based initiatives to other economic, social and cultural contexts, such as high vs low income countries, urban vs rural areas, and formal vs informal markets. In other words, attention to the local context is essential in diffusing technology regarding relevance to the problem, infrastructure, digital literacy and other user competences. Users should be involved in the technological design process to ensure relevance and high uptake.

4. ACTORS, POLICIES AND INSTRUMENTS IN FOOD-WASTE REDUCTION INITIATIVES

Any initiative, policy or actor addressing food waste should follow the food-waste hierarchy (see Chapter 1) where the first priority should be to prevent waste by addressing the sources and causes of waste. The second priority is to set up channels for reuse of surplus food for human consumption, before the third option of food recycling (into animal feed or compost) is sought out. Lastly, energy recovery followed by disposal are the least preferred options.

Various initiatives addressing food-waste reduction at consumer level have proven successful. This section reviews a range of such real-world initiatives, emphasising the most prominent or promising ones that offer important learnings for replication or upscaling. The initiatives show extreme variation, in terms of the actors driving or participating in the initiative, the aim (e.g. prevention or recycling) and approach (e.g. top-down vs bottom-up), the target group (individuals, households, retailers, food service providers, etc.), the instruments (including policies) deployed, the scale of the intervention, and the political, socio-economic and cultural context. Not surprisingly are there also large differences in outcomes in terms of type and amount of waste reduced.

Figure 4.1. The key building blocks of food-waste reduction initiatives: actors and partnerships, instruments, technologies and outcomes in relation to the food-waste hierarchy.



Initiatives can address individual or system-level factors of food waste, but are more likely to be effective if they address the social practices related to food waste, as well as both individual and system-level factors (see Chapter 2). Technologies are optional and have the potential to enable and accelerate the intervention.

It is not possible to account in full here for this rich and multifarious diversity in consumer food-waste reduction initiatives. Instead, we develop a schematic overview of the key elements or building blocks of such initiatives, shown in Figure 4.1, which illustrates the variation in actors and partnerships, the typical type of instruments they employ and the outcomes in relation to the food waste hierarchy. Technologies are an optional component that can enable and accelerate the interventions and outcomes in relation to food-waste reduction.

Following the schema in Figure 4.1, this chapter first discusses the role that different actors and partnerships play in moving forward the consumer food-waste reduction agenda, including government, business, civil society and international organisations. We then present the range of typical instruments deployed or tested by the different actors and partnerships to reduce consumer food-waste in settings in and outside the home, including public policy and regulation, voluntary agreements, and information-based and behaviourally informed initiatives, while acknowledging that there will be overlaps between them. As this analysis concerns mainly instruments for waste prevention and re-use, the following section 4.3 then highlights the waste recycling and recovery initiatives that can be deployed once prevention and reuse have reached their limits. The final section before the conclusion summarises evidence on the cost-effectiveness of food-waste reduction initiatives.

There is no gender-disaggregated data on the design, implementation and impacts of these initiatives. This information would nonetheless be useful to assess the gender implications of food-waste initiatives, identify gaps and challenges and improving the effectiveness of such initiatives, given that gender still plays a big role in the organisation and functioning of food systems in large parts of the world.

A note on geographical representation is warranted before we continue. Most of the interventions discussed here are from high-income countries, due to the scarcity of information from middle- and low-income countries.[5] Chapter 5 presents experiences from food-waste initiatives in five cities in different world regions.

4.1 Actors and partnerships in food-waste reduction initiatives

This section provides an overview of the role played by various types of actors and partnerships in preventing, reusing or recycling food waste, i.e. government, public-private partnerships, industry, grassroots and international partnerships. We illustrate with examples of prominent initiatives from different contexts in which these actors deploy technologies and other instruments to achieve specific food-waste reduction goals. The discussion reveals a great diversity in actors and actor constellations pushing the food waste agenda. It also underscores the imperative of building strong partnerships involving both business, the public sector, civil society, research and international organisations to make interventions that pave the way for more sustainable food systems and consumer practices at scale.

4.1.1 GOVERNMENT-LED INITIATIVES

Governments at all levels (national, regional and local) play a significant role in avoiding or reducing food waste. The specific role played by national and local governments, respectively varies across countries depending on the specific institutional set-up and distribution of responsibilities and powers across local and national governments. However, in general, national governments are responsible for setting the direction and general framework conditions for creating a new pathway for sustainable food consumption.

National governments play a key role in setting the direction for food-waste reduction through national targets, rules and guidelines for change. Governments' responsibilities in this regard also include implementation of policies and the development of action plans, as well as providing the necessary financial support in reaching SDG 12.3 (see Chapter 1). In addition, measurement of food waste is a prerequisite for measuring progress and creating knowledge of where the issues persist along the food-waste chain, also being a responsibility of national governments. It has also been argued that the support and intervention of governments are central for other actors, such as industry, public-private partnerships (PPP) and the grassroots, to succeed in their efforts [39,143,144].

Hence, national governments tend to play a key role in all initiatives addressing food-waste prevention. For example, Thailand's Environmental Quality Management Plan (2017-2022) calls for unified efforts to support food-waste reduction by the public and private sectors [145]. It also calls for a clear strategy to reduce waste across the entire food supply chain, from production, distribution, transportation and processing in the agricultural industry and food businesses to the household level. Uganda's Nation Development Plan III (NDP III) provides for the establishment of food-technology incubators and a national food chain management system. The Qatar National Food Security Strategy (2018 – 2023) included food waste reduction as one of its pillars [146].

Prevention of food waste is also of immense importance for local governments, cities, municipalities and state governments [147–149]. Since local governments are usually responsible for waste management, cities and local governments should have an interest in reducing food waste by implementing food waste-prevention initiatives. A growing number of local decision-makers across the world have already recognised their responsibility and placed food-waste reduction goals on the political agenda, *inter alia* through global partnerships between cities (see section 4.1.5). Likewise, agencies such as the United States Environmental Protection Agency have developed detailed guidelines and toolkits to local governments on how to prevent food waste.

5 *Based on a review of 324 articles from 2006-2017, Reynolds et al. [25] identified 17 studies of interventions that achieved food-waste prevention at the consumption stage of the supply chain (household, community, hospitality, hotels, canteens), only one of which was from a developing country (Thailand), while the remainder were from the USA, Europe or Australia. In this chapter we identify other, more recent studies of interventions from middle- and low-income countries.*

A detailed guide on 'Food: Too Good To Waste' aims specifically at determining how local governments can support behaviour change by consumers and other individuals to prevent waste [150]. Developing countries are also taking actions.

In section 4.2 below, we explain in more detail the policy areas that are the focus of government-led initiatives, namely measurement, date-marking, redistribution of surplus food and wasteful consumption behaviour.

4.1.2 PUBLIC-PRIVATE PARTNERSHIPS

Public-private partnerships (PPP) are collaborative arrangements between a public authority and private-sector companies used to finance, build and operate projects, often with large-scale infrastructure, but also service to the population [151]. Other stakeholders, such as NGOs and research institutions, can also be involved. PPP are useful arrangements because they create shared ownership in solving problems and can create high visibility and impact because of high levels of legitimacy. They are also used to minimize the risks to private-sector companies when they invest and engage in uncertain projects (see e.g. Box 4.7).

Companies appear generally favourable to committing to their targets in public-private partnerships beyond the voluntary agreements they may have signed. Among the reasons are corporate social responsibility (CSR), the company's reputation, pressure from its customers, the opportunity to make financial savings and the implicit 'threat' of legislation [152]. Policy support plays a crucial role at the early stage of the partnership in bringing operators together, providing support, part-financing and visibility.

Public-private partnerships dedicated to reducing food waste are usually organized at national levels and run over several years. A prominent example of a national public-private partnership is the Courtauld Commitment, launched in 2007 by the United Kingdom government [153]. At the centre of the initiative was the large-scale media campaign 'Love Food Hate Waste' run by the Waste and Resources Action Programme (WRAP). Between 2007 and 2012, the UK achieved a 21% reduction in household food waste. Driven by the success and endorsed by the launch of the UN SDGs, the partnership entered a second period in 2015. Under the Courtauld Commitment 2025, efforts to broaden the partnership and to achieve further reductions in food and drink waste in the UK are ongoing.

The Courtauld Commitment. Photo credit: [154]

In the national partnership Denmark Against Food Waste, several of the biggest Danish food suppliers and stores have agreed to create more transparency around food loss and waste and actively work to reduce individual levels [155]. Concretely, they measure and publish data on the amount of annual food loss and food waste and take steps to reduce the amount of wasted food. Three Danish supermarket chains achieved a reduction of 28%, or 12,000 tons, over the period 2014 to 2017. Signed in 2013, France's National Pact for the fight against food waste can be seen as an important negotiating phase before the country voted its food-waste law in 2016 [156].

The Pacific Coast Collaborative (PCC) is a public-private partnership that includes companies and cities along with states over large parts of the US West Coast [157]. It has created the Pacific Coast Food Waste Commitment (PCFWC), a public-private partnership and voluntary agreement featuring large food businesses alongside local, state and provincial governments. PCFWC members work collaboratively toward a shared ambition of effective, industry-wide actions that prevent and reduce wasted food, building upon existing food-waste reduction platforms and commitments [158]. Further public-private partnerships with the aim of reducing food waste are currently expanding in many countries.

4.1.3 INDUSTRY-LED INITIATIVES

Different types of business (including food processors, distributors, retailers, services, etc.) are playing a decisive role in influencing consumers' food-waste behaviour. Nevertheless, for many businesses food waste is not a high priority. The main reasons are that businesses are not aware of the extent and nature of food waste related to their product group(s) or of the true costs associated with food waste. Companies may only see the costs associated with waste-disposal fees, instead of assessing the true costs associated with food waste, such as the costs for raw materials and added value in the process, such as water, electricity, labour and production capacity [159]. Finally, companies are challenged in finding solutions that can address food waste at the consumer level from their position in the value chain.

Other businesses give a high priority to food-waste prevention, mainly because they have understood the true costs of food waste for their own business area [23], and not least the consequences and costs of any negative public perceptions of their acting inappropriately in relation to food waste.

Finally, a new type of business is entering the food system, acting as a 'loop entrepreneur' to close the resource cycle by feeding surplus food back into the food system through re-distribution channels. This business model is built around food re-distribution, where food waste is treated as a resource through which money can be made, while also addressing an important environmental challenge and delivering socio-economic benefits in the form of employment, incomes, improved nutrition, etc.

There are several ways in which companies help consumers reduce food waste. Private companies play a decisive role in developing and deploying technological solutions to reduce or avoid food waste at consumer level. Technology suppliers rely on close collaboration with engaged retailers, food-service providers and consumers to foster user-driven innovation processes and to learn from technological prototypes and solutions in function.

Contracts between supply-chain operators can be designed to include, in a voluntary and collaborative form, enablers for food-waste prevention at the level of consumers and operators. Contracts between retailers and suppliers can include requirements regarding, for example, packaging, labelling and pack information. Retailers can commit to helping customers purchase the right amounts by offering different pack sizes. Companies can also provide information to consumers through various communication channels (newsletters, on-site messages, customer magazines, social media etc.).

Canteen lunch buffet using IoT scales. Photo credit: FooDOP

The hospitality sector can implement monitoring systems to map the stage at which they waste food and make use of IoT technologies to monitor stocks of perishable food to make sure it is used before it goes bad (see Box 4.1).

Likewise, canteens and restaurants can reduce food waste related to buffet servings or by offering smaller portion sizes [25,160] (see Box 4.2).

Box 4.1. Measurement as a basis for reducing food waste in hotels and conference venues

Measuring food waste presents many challenges to the food-service industry. Two of the most common challenges are what to measure and how to measure consistently to create valid data and ensure food production is managed.

FoodWaste is a digital tool that helps organize and simplify tasks and organization concerning food-waste measurements. By setting a manageable design and actual target amounts divided into customers, companies using FoodWaste align themselves with the rest of the industry and focus their attention on where the waste is occurring.

As an example, the hotel and conference chain Comwell in Denmark wanted to know the exact origin of their food waste and found that systematic measuring was the way forward. Using the FoodWaste technology and the data and reports it generates, they were able to determine whether the origin of the waste was mainly the buffet or the guests' plates, and they were also able to pinpoint the actual produce that was the source of most of the waste.

Using the reports to keep an eye on their registration frequency enables them to create data that are valid and reliable. The data collected so far has thus enabled Comwell to identify where to target their efforts to reduce food waste. The company has thus set itself a target of reducing food waste from the breakfast area by 25%. From earlier experience, they expect to be able to save money on produce, time spent in food preparation and to reduce their climate footprint.

Source: Mette T. Rasmussen (personal communication) and [161]

Photo credit: eSmiley

In a buffet-serving context, there are several strategies to nudge customers to avoid overserving by introducing smaller plates, tray-less dining, staffing the buffet, pre-plating items or pay-by-weight systems. Smaller plate or portion sizes are the only strategy for which the literature is rich in quantified empirical evidence [25,162]. One study shows that smaller plate sizes reduce plate waste from buffet servings by 20% [163]. Another study has shown that smaller plate sizes reduce food waste by 57%, although this study also showed that the food consumed was reduced by 31% [164]. Finally, a study from São Paulo, Brazil, compared on-plate food waste for different restaurant configurations [165]. The on-plate food waste was lowest in restaurants offering variable price (per weight) buffet services that gave consumers a strong financial incentive not to waste food, as well as the ability to control their portion size. In contrast, the fixed-price table service, which offered neither incentive nor ability, resulted in plate waste that was three times higher on average [165].

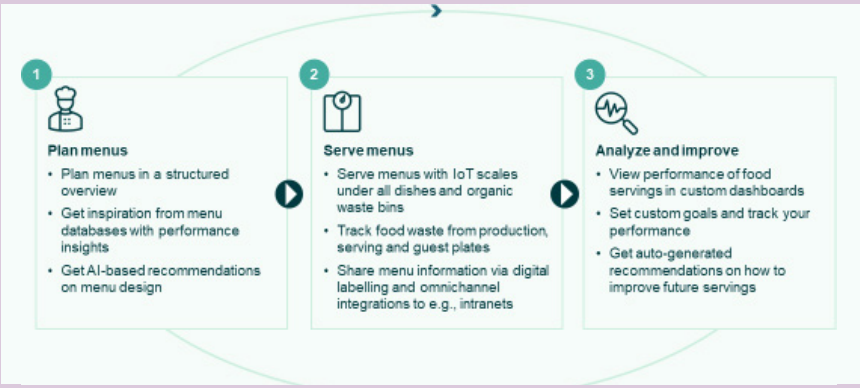
Box 4.2. Reducing food waste in food service and catering through IoT scales and a smart menu-planning and tracking platform

It can be challenging for food-service companies to know what people want and how much to serve every day. COVID-19 has certainly not made it easier, as the work location has become more flexible. In catering, where food is delivered from a large central production kitchen, the caterer is not even present on site to see what and how much people eat.

FooDOP is a smart menu-planning and tracking platform that is enriched by data from IoT scales. IoT scales are placed under all dishes and organic bins to measure the consumption of and left-overs from each dish. The data provide granular insights into consumption and waste from production, servings and guests' plates. All data on e.g. food waste, the carbon footprint and guest preferences are reported on custom dashboards. The platform also gives the chef AI-based recommendations on many aspects of menu-planning, including quantities, sustainability and how to tailor menus to guest preferences.

Photo credit: FooDOP

Data from Denmark show that up to 50% of food purchases are wasted in food-service companies. The distribution of food waste varies, but generally 15-25% is production waste, 40-50% comes from the serving and 20-30% comes from guests' plates. During the COVID-19 pandemic some foodservice companies moved from buffets to portioned servings, where a lot of waste is moved from the serving to plate waste, which can be more challenging to track and see. With FooDOP, food waste is typically reduced by 40-70% within 3-6 months. The environmental footprint is typically reduced even more through more sustainable menus (e.g. chefs are given access to a large database of recipes and performance data).



Source: Nichlas Saul (personal communication) and [166]

4.1.4 GRASSROOTS INITIATIVES

Grassroots initiatives can play an important role in reshaping the everyday food-consumption practices of individuals and households [167]. The reason is that grassroots initiatives are a form of bottom up-driven environmental activism that aims to change everyday practices of consumption. Grassroots initiatives are typically collaborative social undertakings organised at the local community level and characterised by a flat hierarchy and high degree of participatory decision-making [168].

Grassroots initiatives within the area of food waste are driven by either environmental or social concerns or both. They pursue a variety of activities [167]. Some initiatives aim to prevent food waste (the top priority of the food-waste hierarchy) by providing knowledge and planning tools to avoid surplus food in households. Many others focus on the second priority of the waste hierarchy, namely re-use of surplus food through redistribution, often to people affected by poverty (see section 3.4 and Box 5.3). These initiatives typically focus on 'rescuing' edible food waste from, e.g., supermarkets (dumpster-diving), collecting leftover crops from farmers (gleaning), or making arrangements with downstream actors (retailers, wholesalers, processors, food-service companies etc.) that generate large amounts of surplus food to donate to organisations that then redistribute it to people in need. Finally, some grassroots promote urban farming in shared open spaces, where members can grow vegetables for own consumption or to be shared with the community. These initiatives build on sharing of knowledge and skills with respect to gardening and cooking of seasonal vegetables.

Although grassroots initiatives often aim to develop sustainable consumption patterns for households, they can also lead to changes and capacity-building at the community level and may potentially lead to infrastructure changes in society through social innovation and experimentation [168].

However, grassroots initiatives often face several challenges. First, building and maintaining grassroots initiatives is difficult because, when they grow in size, the consumer's experience, facilitated through values such as personalization, trust, tolerance and accountability between participants, may fall.

Second, grassroots initiatives that have been successfully sustained for some time often face challenges in being diffused more widely. Diffusion of grassroots initiatives can happen through three routes: scaling-up (i.e., growing in scale), replication at new locations, or translation into mainstream contexts [169]. Scaling-up is difficult because, when the organisation grows to a certain size, it may exceed the possibilities of self-organization. It is therefore often argued that diffusion through replication at new locations is a more suitable route for sustaining grassroots initiatives [170]. Alternatively, a grassroots initiative's core idea may also be disseminated by mainstream actors adopting the main ideas and integrating them into their own business models.

One emerging social movement is centred on so-called community fridges (public refrigerators) through which food is shared with the aim of reducing food insecurity while reducing food waste. This novel approach has a global reach (except for Africa) and is particularly popular in the UK [171] and the US [172], where community fridges have become more widespread during the COVID-19 pandemic, for example, in New York City [173]. See Box 4.3.

Box 4.3. 'Freedge': sharing surplus food through public refrigerators

Freedge is a sharing mechanism that aims to reduce food insecurity and food waste, building a stronger community. It promotes equal access to healthy food through the installation of community fridges (public refrigerators) that are used to share food and ideas within the neighbourhood [172].

Community fridge in Yishun, Singapore. Photo credit: Darul Makmur Mosque

4.1.5 GLOBAL AND REGIONAL PARTNERSHIPS

Global and regional networks and partnerships have become important platforms for knowledge-sharing and capacity-building by governments and other stakeholders in the food system, such as non-governmental organisations, cities and international organisations. These initiatives are often aimed at improving the understanding of food systems and the causes of food waste. In concrete terms, such global and regional partnerships often support the activities of developing standards for measurement and share experiences and learning from policies and initiatives on sustainable food systems. These networks help make the huge challenge of food waste visible through their activities and develop and diffuse knowledge across the world.

An example is UNEP´s initiative Global Opportunities for Sustainable Development Goals (GO4SDGs), where UNEP, together with WRAP and the One Planet Network, has launched Regional Working Groups on Food Waste [174]. In addition to providing a platform for capacity-building on the measurement and reduction of food waste, the Regional Working Groups offer peer to peer collaboration between countries as they tackle similar food-waste reduction challenges.

Several global initiatives, such as the C40 Cities Climate Leadership Group and the Milan Urban Food Policy Pact, bring together cities and local governments across the world in order to share knowledge and experiences about best practices. Other important global partnerships include the International Organization for Standardization (ISO), the One Planet network, etc.

4.2 Instruments of consumer food-waste prevention and re-use

A variety of instruments, including policies and regulations, standards and labelling, voluntary agreements and information-based approaches, have been developed and deployed by actors aiming to minimize food surpluses through prevention or reuse. Figure 4.1 illustrates the main categories, discussed below.

4.2.1 PUBLIC POLICY AND REGULATION

In this section, we describe public policy and regulation by government units aimed at influencing consumers' behaviour related to food waste. In principle, public policy and regulation can influence (directly or indirectly) all the individual and system-level factors and social practices that are responsible for the food-waste behaviour described in Chapter 2. Based on a review of the literature and of initiatives addressing food-waste prevention, we have identified some recurrent themes in this respect, namely measurement, date-marking, redistribution and wasteful consumption behaviour. In addition, governments make use of public-private partnerships, information campaigns and broad initiatives like zero waste or circular economy policies to target broader issues that also have relevance for consumer food-waste behaviour.

4.2.1.1 MEASUREMENT STANDARDS AND INITIATIVES

A prerequisite for understanding the effects of all other food-waste reduction interventions is solid data on the quantity, quality and sources of food waste. One huge challenge in designing the best food-waste interventions is that data on food waste are lacking or are inadequate in many regions of the world. Research shows that consumers do not know how much food waste they generate [115,116]. Moreover, it is important that data are comparable across countries and regions, and that they provide a clear picture of the sources of food waste that characterise a specific food system in a given country or region. Without such data, it is difficult to know where to start when designing food-waste interventions.

Measuring food waste and creating knowledge of the baseline from which progress should be measured is a prerequisite not only in designing effective interventions [1,143] but also in delivering on the targets set out in SDG 12.3. A great amount of work has gone into developing the Food Loss and Waste Accounting and Reporting Standard [175], which lays the ground for the Food Waste Index report, published for the first time in 2021, and the global Food Waste Atlas [176] developed by WRAP and the World Resources Institute (WRI). The Food Waste Index provides a common methodology for measuring food waste and tracking progress on SDG 12.3. In 2021 ISO launched a working group to develop a common international standard to reduce food waste. The standard should ensure a common understanding of what food waste is and how it is measured, making it easier to compare and set goals across organizations and countries.

Another supra-national initiative on measurement is the EU Platform on Food Losses and Food Waste, which has developed recommendations to public- and private-sector actors regarding the measurement of food waste by increasing the availability, consistency and transparency of data [177]. Similarly, national and local governments across the world have initiated processes to establish their baseline and measurement schemes [147,148]. Through the C40 initiative, many large cities have committed or already developed measurement schemes to follow the progress in reducing food loss and waste by 50% from a 2015 baseline [147].

Countries and cities could make the best use of these tools in building and improving their data systems for food-waste measurement and analysis.

Finally, systematic measurement is a key component of many of the concrete food-waste initiatives reported in this and the previous chapter. Here, single firms or PPPs have developed technologies such as smart bins and smart scales, as well as data analytics and data platforms, that enable quite precise monitoring of the quantity and quality of food waste, especially in the food-service sector, but also in households. Important lessons can be learned from these initiatives in developing measurement and monitoring schemes on the city and national scales. More work could be done to streamline food-waste measurement and improve the capacity of countries, cities and businesses in improving their data collection and analysis. UNEP's Regional Food Waste Working Groups are helping 25 countries measure baselines and develop national food-waste prevention strategies.

4.2.1.2 DATE LABELLING

Date labels influence consumers in their selection of food at the point of purchase, as well as its subsequent consumption and decisions to throw away food. The most common date labels distinguish between quality (Best Before) and safety ('use by'/'expiration date') (see Box 4.4), having been established by the FAO-WHO Codex Alimentarius Commission as the first global standard for date-marking in 1985. Nevertheless, there is considerable variation in date-marking practices around the world and even within countries [178,179]. The lack of a harmonized practice for date-labelling contributes to misunderstandings in the market place, misuse by manufacturers and confusion for individuals and households, and causes inappropriate responses [179,180]. For example, research has shown that about 50% of European consumers do not understand the meaning of date labels, while in the Netherlands about 15% of what people throw out at home is related to misunderstanding them [181].

The consequence is that large amounts of food are wasted due to misconceptions regarding date labels. For example, a study by the EU Commission [180] estimated that 10% (equivalent to 8.8 million tons) of the annually generated food waste in the EU is linked to misunderstanding date-labelling.

Moreover, manufacturers have been found to be over-cautious when applying durability dates and specifying significant safety margins [97]. This is because they are primarily responsible for ensuring their products are safe when they are consumed, yet they do not control the supply chain further downstream and therefore apply a margin of safety to durability dates [97], resulting in food that is safe and of good quality to be discarded at the retail and consumption stages.

Box 4.4. Date labels explained

Use-by dates are about safety

A use-by date on food is about safety. This is the most important date to remember. You can eat food until and on the use-by date but not after. You will see use-by dates on food that goes off quickly, such as meat products or ready-to-eat salads. For the use-by date to be a valid guide, you must carefully follow the storage instructions. For example, if the instructions on the packaging tell you to refrigerate after opening, you should keep the food in a fridge at 5°C or below. After the use-by date, don't eat, cook or freeze your food.

Best-before dates are about quality

The best-before date, sometimes shown as BBE (Best Before end), is about quality and not safety. The food will be safe to eat after this date but may not be at its best. Its flavour and texture might not be as good. Best-before dates appear on a wide range of foods including, frozen foods, dried foods and tinned foods. The best-before date will only be accurate if the food is stored according to the instructions on the packaging.

Source: [182]

Photo credit: Shutterstock

4.2.1.3 REDISTRIBUTION OF SURPLUS FOOD

Redistribution of surplus food is another central theme for local and national governments across the world in their battle against food waste. Governments use either regulations enforced by laws or softer incentive schemes to make supermarkets, restaurants and food producers donate excess or surplus food products. In 2016, France became the first government to ban supermarkets from throwing away or destroying unsold food by making it mandatory for those larger than 400 m2 to donate unsold food to charity or foodbanks [183]. The French law was extended to mass catering and food production in 2019. At the softer end of the spectrum is the Australian government, which has chosen to support Food Rescue Charity organisations in handling food surpluses without imposing any legal obligations on businesses [184].

Governments can also create incentive schemes for food donations by amending their tax-policy frameworks. In the US, the federal government has recognised the importance of food donations and uses the tax and legal framework to incentivise businesses to donate food. This is done through generous tax incentives to food donors by way of enhanced deductions that exceed the value of the food donated. In some European countries, such tax incentives have broadened the scope to include the cost of logistics, storage and transport services related to food donations [185].

Moreover, some countries, namely Argentina, Canada, Peru and the US, have adopted liability protections to mitigate the concerns of food donors and intermediaries that they will be found liable if the final recipient falls ill after consuming donated food [186].

Local governments also play an important role in bringing local private-sector and grassroots actors together in different schemes to encourage the redistribution of unsold and surplus food. For example, the Milan Urban Food Policy Pact of 2015 aims at building sustainable and inclusive food systems by focusing on 'social and economic equity' in food systems [187]. Today the food pact has more than 200 signatories from mayors from around the world, who actively work on creating incentive schemes to encourage donations of food surpluses. Similarly, in Pakistan, the Punjab Food Authority (PFA) has passed the Disposal of Excess Food Regulation 2019, which requires food operators (restaurants, catering services etc.) and manufacturers to donate excess food to the underprivileged as part of the fight against hunger [188]. The intention behind this regulation is dual – aiming both to avoid food waste and to improve food access for people in need. Local governments can also integrate the requirements for addressing SDG 12.3 through public procurement, asking suppliers to donate surplus food to social organisations, which then distribute and process the food. For example, the Public Centre for Social Welfare in Bruges, Belgium, is committed to including SDG12.3 among its criteria, in addition to price and quality, in its tender specifications for awarding contracts [189].

4.2.1.4 ADDRESSING WASTEFUL CONSUMER BEHAVIOUR

More recently, governments have initiated policies and regulations targeting 'lavish' consumption behaviour related to eating and dining practices, which tend to generate excessive food waste. Such behaviour is often culturally determined. Research has shown that in some cultural settings, like restaurants or professionally catered celebrations, customers' social food practices result in exceptionally large amounts of food waste [65,66,190]. In South Korea, for example, the array of side-dishes that accompany a traditional meal are often left uneaten, contributing to very high rates of consumer food waste [191]. Such practices have caused governments to introduce laws to regulate better consumption behaviour. For example, Chinese lawmakers have adopted an anti-food waste law that aims to reduce the approximately 18 million tons of food wasted every year in China's urban catering industry. The law allows restaurants to charge customers a disposal fee for leaving excessive leftovers behind, and restaurants will receive a warning and subsequently a fine of up to 10,000 yuan (US$1,546 dollars) if found guilty of behaviour that can lead diners to wasting food.

In sum, public policies and regulations targeting food-waste prevention cover many different themes and make use of different types of instrument. Within the same intervention area, our review shows that governments make use of policy instruments from both ends of the spectrum, that is, from hard regulation to softer incentive schemes.

4.2.2 VOLUNTARY AGREEMENTS

Voluntary agreements are alternative policy instruments belonging to so-called 'soft law' and 'new public policy instruments'. In the context of environmental sustainability, they are schemes in which public- and private-sector organisations make commitments to improve their environmental performance without the need for legislation or sanctions [143]. They include self-regulation and commitments developed by the industry and/or other stakeholders and implemented at their own initiative or in response to policy developments [39]. In these circumstances, public authorities tend rather to steer the issue, acting indirectly as a facilitator with less interventionist forms of public regulation, instead of being directive and using authoritative power through instruments of the 'command and control' type [192].

Through voluntary agreements, food companies can acknowledge the role they play in the generation of food waste and commit themselves to act to minimize it. Food manufacturers, retailers and food-service companies themselves act to reduce food waste, but they also act on food waste arising upstream – that is, at their suppliers – just as they do on food waste arising downstream, in consumers' homes.

The effectiveness of voluntary agreements on consumer food waste is difficult to measure, as such agreements are part of the broader enabling environment of food-waste reduction and tend to become effective by combining the instruments involved (information, nudging, technology etc.).

4.2.3 INFORMATION-BASED APPROACHES (AWARENESS-RAISING AND INFORMATION-SHARING)

Information has been widely used with the aim of influencing people's behaviour. According to [39], initiatives based on information cover the transfer of knowledge, education and counselling. They assume that providing information creates problem awareness and changes behaviour. A variety of initiatives make use of information, from information and awareness campaigns and social-norm campaigns via educational efforts and skills training to prompts and labelling, feedback and self-commitment. They can be implemented at various scales, on the national or international scales in the case of campaigning to situational settings, e.g. in a university canteen or a shop. ICT or digital tools are widely used [75,136]. Examples of 'informative' consumer apps include integrated food planning, shopping and recipe apps, which can help in planning for food, its acquisition and finding recipes. 'Reminder and storage apps' remind consumers of the expiration date of a product. 'Food-sharing apps' provide access to infrastructure for food-sharing. See section 2.3.

Strategies that provide information alone are likely to belong to the least successful interventions intended to foster pro-environmental behaviour [193]. For food waste particularly the evidence is scarce, though a few examples of effective information-based interventions stand out. One study revealed food-waste reductions of up to 28% as a result of a collaborative in-home experiment with householders, but the finding needs to be taken with caution due to the small sample size (n=5) [25]. A study of another intervention targeting 108 German households, with a similar size control group, achieved a waste reduction of 12%. It did so by providing participants with recommendations for the different household food practices (e.g. planning grocery shopping in advance), in combination with a public commitment and goal-setting measure whereby participants were asked to indicate their willingness to follow some or all recommendations during the following weeks [194].

A third study found that information provided by a retailer through a variety of communication channels (in-store magazine, e-newsletter, social media site, product stickers and in-store demonstrations) and repeating messages over time had a significant effect on reducing food waste in customers' homes [195]. However, many of the reviewed studies relied on methods of self-reporting, used in particular to assess household food waste, so could be biased by under-reporting.

Initiatives using *social norms* in the field of food waste provide information about desired behaviour or attitudes in their reference group, knowing that people tend to conform to the majority. This can be done in the form of demonstrations of everyday food practices, such as planning, shopping, storing, portioning and leftover reuse, in order to demonstrate socially desirable behaviour and show to build household skills. The influence of social norms has not as yet been well understood, but there is some evidence from academia that social norms exert social pressure, which in turn may determine food-waste behaviour [196].

Prompts, in the form of short written messages in a restaurant about the use of doggy bags, made users take home their leftovers more often than in situations without prompts [197]. Written messages were also effective in a six-week experiment at a university dining hall, resulting in a reduction in edible food-waste of 15%. The addition of a more personalized, feedback-based message did not stimulate additional change beyond that of the prompt message [198]. Initiatives using self-commitment or feedback have been very little studied.

Overall, research should intensify efforts to study the effectiveness of information-based initiatives on consumer food-waste behaviour, both for information used alone, as in the case of the widespread information and awareness-raising campaigns, or in combination with other types of behavioural intervention using social norms, prompts, etc.

Box 4.5. Mobilizing young people to adopt sustainable lifestyles and avoid waste

The Anatomy of Action (AOA) campaign is a UNEP initiative launched under its Sustainable Lifestyles and Education framework. AOA translates the science behind SDG 12 into everyday individual actions under five domains: food, stuff, move, money and fun. #UseAllYourFood is the second task under food, and addresses food waste by reducing organic waste going to trash heaps and landfill, improving soil fertility and increasing equitable access to fresh food. The overall objective of the AOA is to harness the power of social media to engage and mobilise as many young people (i.e. tomorrow's consumers) as possible to swap their unsustainable consumption and lifestyle patterns for sustainable ones. Source: [199]

Photo credit: Anatomy of Action

4.2.4 CONSUMER INFORMATION TOOLS, INCLUDING ECOLABELING

Consumer information tools, such as ecolabels and sustainability standards, are a particular type of information-based approach designed to guide consumers towards food products that have a better environmental performance (including in the use and disposal phases) and to inform consumers of the environmental impacts of their consumption choices [200].

Very few consumer information tools currently cover food waste. Date labels such as Best Before and 'use-by' (see section 4.2.1.2) are the main guidance consumers have regarding the disposal of food, but they can be misleading and actually increase food waste if not accompanied by clear explanations. Companies need to use clear and relevant messaging to provide product information. They also need to ensure the environmental credibility of the information to avoid confusion and distrust, which will undermine the effectiveness of guiding consumption choices. There is also a need to inform consumers better about actions that can reduce food waste after purchase, such as storage, product lifetime extensions and best cooking practices. The UNEP & ITC Guidelines for Providing Product Sustainability Information outlines ten principles that should be followed when providing sustainability information to consumers and recommend the employment of life-cycle thinking when assessing the sustainability impacts of products [201].

4.2.5 BEHAVIOURALLY INFORMED APPROACHES (NUDGING)

The use of behaviourally informed approaches to change people's behaviour, also called nudging, has gained popularity in policy. Prominent fields are health and pro-environmental consumer behaviour, giving rise to so-called behaviourally informed policies [202]. Nudging involves small, low-cost, choice-preserving and low-intrusion approaches to steer people's choices. A nudge is defined as 'any aspect [...] of the choice architecture that alters people's behaviour in a predictable way without forbidding any options or significantly changing their economic incentives' [203]. The aim is to influence consumer behaviour without coercion, leaving consumers with the idea that they are enjoying freedom of choice. While choice is guaranteed, it is nonetheless influenced by 'choice architecture', that is, designing how choices are presented to consumers. Examples of nudges tested in the field of consumer food waste are social norms, warnings and reminders (partly overlapping with information-based interventions) [204], plate sizes and portioning [163,205]. Most of them were tested in settings of out-of-home consumption.

There is a small but growing body of empirical evidence that nudges and choice architecture achieve effects in consumer food waste when tested in field experiments. Only some studies were able to quantify them, possibly because intervention through nudging is easier to perform in out-of-home settings than in peoples' home. When plate size was reduced in the study by [164], food-waste reduction was largest (57%) but there was also a 31% decrease in the amount of food consumed. The study by [163] reported a reduction of 20% in food waste at a restaurant buffet when two nudges – reduced plate size and displaying a sign to invite guests to help themselves more than once – were used. The effects on food consumed were not reported. A reduction in food leftovers was enabled by moving to smaller portion sizes in two studies [160,206], one of which reached a 31% reduction by reducing portions of French fries [160], a change that was not even noticed by the majority (70%) of consumers, leaving satisfaction unaffected.

Not only plate or portion size, but also plate disposability can influence the amount of food wasted. A 51% reduction in food waste was achieved by using permanent rather than disposable plates [207], but the latter were associated with stopping eating sooner. It could be that the effectiveness in the reduction of food waste was due to greater consumption, not smaller servings, therefore causing undesirable effects on consumer health through overconsumption.

Other studies tested combined interventions. An experiential learning project consisting of reduced portion sizes, smaller serving utensils and educational messaging was implemented in a university dining hall with the objective of reducing food waste while building student capacity. However, it produced no effect on food waste [208].

While nudges have been shown to be successful, low-cost, easy to implement and choice-preserving, and therefore are well accepted by consumers, some downsides are worth mentioning here. First, there is little knowledge about whether nudges have any long-term effects on consumers' habits and deeply-rooted norms and practices related to food waste. Second, policy using nudges is criticized for wanting to steer people toward certain choices by stimulating unconscious psychological processes, rather than helping them learn to make better decisions by developing deliberate rational faculties [209]. The consequences could be a loss in people's learning and decision-making capacities.

However, advocates of nudging argue that it is not a matter of either/or but of combining nudging and education about food waste in order to help people achieve their own goals of reducing food waste. In this context, nudges designed to promote health, safety and environmental protection do receive strong approval rates in surveys carried out among people, mainly in high-income countries [210]. Finally, effective nudging depends on trust in public institutions, and so large differences are observed across countries in the approval rates of nudging initiatives and their effectiveness.

4.3 Recycling and recovery infrastructure to manage unavoidable food waste

Once food-waste prevention and redistribution of surplus food come to their limits, remaining food waste requires management options, which are cost-effective while limiting the environmental impact. In food systems, recycling has a long tradition; for example, leftover food and kitchen waste are commonly fed to livestock in rural areas and close-by urban centres in low- and middle-income countries [211,212]. Driven by the circular economy, waste and renewable-energy policies, waste-recycling and recovery infrastructure is developing in many countries. High-income countries like Japan and South Korea (see Box 4.6) have been leaders in the collection and treatment of industry and household food waste, partly driven by strong resource efficiency policies.

Box 4.6. A pay-as-you-throw food-waste recycling system in South Korea

At 130 kg per person per year, South Korea has one of the world's highest rates of food wastage, causing increasing pollution to the marine environment and methane emissions from sewage plants and landfills. To confront this, the government has introduced policies and programmes to increase food-waste recycling rates, 2% in 1995. In 2005, landfilling of food was banned, and in 2013 a scheme of compulsory food-waste recycling was introduced. The scheme is based on the use of biodegradable bags, which households must use to dispose of all their food waste. Households pay a fee for the bags, and the charge for disposal depends on the weight of the waste; they are thereby encouraged to reduce both the amount of waste (by 30% to date) and its moisture content (which is about 80% for food waste), which in turn reduces the cost of municipal waste collection. The bag charges pay for 60% of the cost of running the scheme. As a result of this pay-as-you-throw scheme, the recycling rate increased to 95% in 2019.

The food waste is recycled mainly into compost for use on the country's rapidly increasing urban farms, and it is also used for animal feed and energy recovery through anaerobic digestion or incineration.

Two key policies laid the foundation for this total transformation of South Korea's management of food waste: 1) The Waste Management Law passed in 1986 introduced for the first time a waste-management hierarchy of reduce, reuse and reuse, among other principles and instruments. 2) the Act on Resource Saving and Recycling Promoting enacted in 1992 introduced the volume-based system for household waste collection outlined above, based on the polluter pays principle, and banned any other form of waste disposal.

So-called smart bins have been an important part of the programme's success. In the Seoul Metropolitan Area, with some 25 million inhabitants, 6,000 such bins have been installed today in public and residential areas. They are equipped with scales and Radio Frequency Identification (RFID) technology, which enables pay-as-you-throw disposal, charging residents using a key-card system with monthly payments. Source: [191,213,214].

Photo credit: Wikimedia

4.3.1 RECYCLING INTO ANIMAL FEED

Driven by sustainable-production goals and cost considerations, in many countries the livestock industry is exploring accessing so far unexploited resources, including a growing interest in food-waste recycling for use as non-ruminant animal feed [215]. There is great potential in this field provided food safety concerns associated with transmissible diseases can be appropriately managed [216]. Using food waste to rear insects, a valuable source of protein, is another, indirect way of recycling food waste into livestock feed.

4.3.2 RECYCLING VIA COMPOSTING

Composting is a widely used recycling option for food waste, creating alterations to the soil and nutrients for fertilizers while reducing landfill. There are small-scale units tailored to peoples' homes, neighbourhoods and businesses, such as the Compost Kitchen [217] and Maeko [218] (see Box 4.7) for composting solutions in the Asia-Pacific region.

Box 4.7. Speeding up the composting of food waste in Malaysia

The Malaysian start-up, Maeko, has developed a machine that rapidly speeds up the composting of food waste in an aerobic environment. By crushing the waste and carefully controlling the temperature, agitation and airflow, the machine can produce a ready-to-use bioorganic compost within 24 hours, reducing waste volumes by up to 80% while avoiding emissions of methane and odours, which would be the result of landfilling. The compost can be used as soil amendment or a soil enhancer in farms and gardens. A variety of industrial-scale composters (see photo) have been developed for shops, food-service companies and institutions, while the latest invention is a small, portable composter for household use, the Munchbot. Source: [218,219].

Industry-scale composter. Photo credit: Maeko

4.3.3 POTENTIAL CONFLICTS BETWEEN RECYCLING AND PREVENTION

From an environmental perspective, keeping food waste out of landfill or informal waste dumps is an important aim, as disposal is associated with high emissions of methane, a powerful greenhouse gas, and the risk of water pollution. The literature has moreover shown that the environmental benefits in terms of climate impacts are greater the higher a management option is located up the waste hierarchy [15] (see Chapter 1). Anchored in national waste policies in the so-called Reduce-Reuse-Recycling (RRR) approach or the waste hierarchy [220], the order of prevention, reuse and recycling yields the best environmental outcomes, though this means disregarding the costs of infrastructure, regulation and social perception. Moreover, as with any closed-loop system, recycling requires food waste to be thoroughly sorted and processed with due regard to the possible safety risks associated with biological, chemical and physical contamination [221].

In practice, tensions may arise between recycling and prevention initiatives, as well as between actors with different objectives. An overall challenge for local governments' activities in addressing food-waste prevention, for example, is the lack of a clear distinction between preventing food waste, as opposed to recycling or reusing wasted food [222,223]. Concurrently, with the establishment of more and more advanced food-waste management systems, interventions related to reducing waste streams may turn into an area of conflict over resources. As a consequence, the emerging organic waste-management industry, driven by circular-economy narratives of 'waste as a resource', may emphasize the business opportunities associated with food-waste recycling [224]. Initiatives to prevent food waste may therefore be perceived as being associated with a loss of opportunities for creating value. As policy has historically addressed individual food-waste management options separately, a coherent and integrated policy framework would be needed to act on the entire system of food waste. Doing so will ensure that prevention, reuse and recycling actions are in line with the food-waste hierarchy and complementary to each other.

4.3.4 RECOVERY THROUGH WASTE-TO-ENERGY AND MULTI-PURPOSE INFRASTRUCTURE

The most common technologies for the recovery of energy from food waste are anaerobic digestion (a biomechanical process) and incineration (a thermal process). Anaerobic digestion of food waste is an attractive alternative to composting, as it yields renewable energy, organic fertilizer and soil amendment. Large-scale biogas facilities treating food and other types of organic waste from households and industry on the city scale are well established in some places. In Oslo, for example, the gas produced in the city's biogas facility is used as a transport fuel by the city's buses, while the digestate is applied to nearby farms. Similar systems are developing rapidly elsewhere, such as in Denmark, where EU and national waste policies, as well as improved biogas support schemes, have been major drivers.

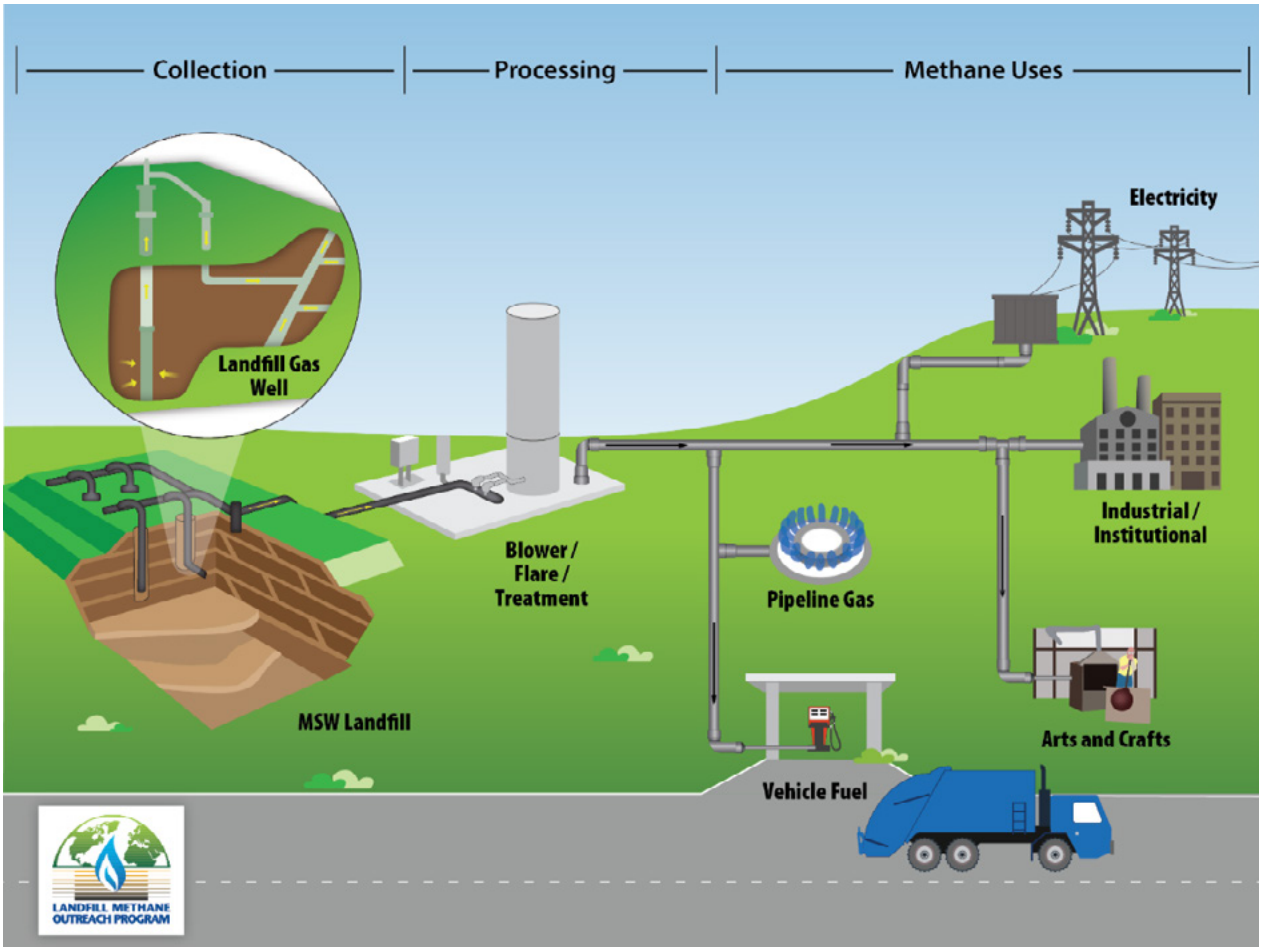
Thermal waste-to-energy (WtE), or incineration with energy recovery, is another way of recovering energy from food waste. Thermal WtE plants are used to treat municipal solid waste (MSW), which often includes unsorted food waste as a major part of solid organic waste. On average, 15.2% of global MSW is treated this way, while 59.8% goes to landfill or other forms of disposal [225]. However, over 80% of thermal WtE plants are located in developed countries, while 90% of collected waste in Africa and Latin America, for example, is landfilled. It is noteworthy that organic waste makes up 53-56% of MSW. However, this waste fraction has a low calorific value and so generates relatively little energy. Thermal WtE plants must therefore depend on high-calorie waste fractions such as plastics to function. Another drawback of incinerating food waste as part of MSW incineration is that the nutrients cannot be recovered, as they are mixed in the ash with toxic substances derived from other fractions. There are, moreover, considerable flue-gas emissions from thermal WtE plants, which require further treatment before emission to the atmosphere. All this suggests that composting or anaerobic digestion are the preferable food-waste recovery options from an environmental perspective.

Finally, solutions for the joint or integrated treatment of organic waste together with waste-water and faecal-sludge management are developing in low- and middle-income countries where affordable sanitation and waste treatment are still needed. In Ghana, for example, the company Safisana collects both faecal and organic waste from urban areas, public toilets, food markets and food-processing industries and transports it to its recycling plant [226]. Here it is processed into biogas (through anaerobic digestion) and organic fertilizer, with the former being used to produce electricity and the latter being applied to vegetable farms. The waste water is turned into clean irrigation water used by local vegetable farmers. One recycling plant can serve 50,000 people, treat 3600 tons of organic waste and 9700 tons of faecal waste every year, and produce 600 megawatt hours of renewable energy and 91 tons of organic fertiliser.

4.3.5 RECOVERY THROUGH ENGINEERED LANDFILL WITH GAS UTILISATION

Unmanaged landfills are a huge environmental problem. The World Bank Group estimates that globally about 2 billion tons of municipal solid waste, including organic waste, is generated every year worldwide, at least one third of which ends up in environmentally unhealthy and unsafe landfills. Landfill gas is a natural by-product of the decomposition of organic material in landfills and is composed of roughly 50% methane (the primary component of natural gas), 50% carbon dioxide and a small amount of non-methane organic compounds. Because methane is a potent greenhouse gas tens of times more powerful than carbon dioxide at warming the atmosphere, landfill gas that remains untreated is a huge problem that needs to be addressed to mitigate climate change [227].

Landfill gas utilization is a process of gathering, processing and treating the methane or other gas emitted by decomposing garbage waste to produce electricity, heat, fuels and various chemical compounds. Instead of escaping into the air, gas from landfills can be captured, converted and used as a renewable energy resource (see graphic illustration).



The above graphic illustrates the collection and processing of LFG to produce methane for multiple uses. First, LFG is collected through vertical and horizontal piping buried in an MSW landfill. The LFG is then processed and treated for use. The graphic shows potential end uses of LFG, including industrial/institutional uses, arts and crafts, pipeline gas and vehicle fuel. Source: [228].

To extract landfill gas, it is necessary to establish a series of wells and a blower/flare-treatment system that directs the collected gas to a central point, where it can be processed and treated depending on its ultimate use. Systems of landfill gas utilization can be implemented as part of the establishment of new landfills or on existing landfills (see Box 4.8). When installing landfill gas utilization on existing sites, a section of an existing landfill is closed off and covered with a fine material to create a so-called 'cell' of waste mass. Usually vertical wells are drilled into the waste mass and the wellheads connected to lateral piping, which transports the gas to a collection header using a blower or vacuum induction system. The captured gas can be converted into energy through an energy-from-waste platform and either produce electricity, medium Btu gas for immediate use, or renewable natural gas.

Box 4.8. Upgrading the Vinča landfill in Belgrade through a public-private partnership

The Vinča landfill in Belgrade, Serbia, is the largest unmanaged open dump in Europe. It absorbs 1,500 tons of household waste and 3,000 tons of construction waste every day.

The landfill is in the process of being transformed into a new waste facility equipped with green technology, enabled through a public-private partnership between Beo Čista Energija formed by Suez (France), the ITOCHU Corporation (Japan) and Marguerite (Luxembourg) with the City of Belgrade with the support of the International Finance Corporation (IFC), the European Bank for Reconstruction and Development (EBRD) and the Development Bank of Austria (OeEB). As part of the project, a new sanitary landfill will be built, together with a waste-to-energy plant and a construction-waste recycling unit. It will sell the electricity and heat generated from the waste as substitute for fossil fuels, thus reducing GHG emissions.

Source: Gordana Jelenic, BCE (personal communication) and [229]

Work in progress on the Vinča landfill, June 2021. Photo credit: Beo Čista Energija

4.4 Cost-effectiveness of food-waste reduction interventions

Financial savings (see Chapter 2) are a strong motivator for business actors and governments to take action against food waste. Nevertheless, the costs and returns on investments are crucial parameters for a company or local or national government when it comes to setting priorities in funding. A WRI-WRAP-led report for the Global Champions 12.3 initiative analysed the financial impacts of historical food loss and waste-reduction efforts conducted by a country, city or company [230]. The results show that the financial benefits of taking action often significantly outweighed the costs.

For example, a benefit-cost ratio can be calculated for the Courtauld Commitment 2025 [153], a public-private partnership in the UK. From 2007 to 2012, the total cost of implementing the initiative was £26 million, while the total financial benefits to the government and households arising from savings associated with household purchases and food-waste disposal costs were estimated to exceed £6.6 billion. The benefit-cost ratio therefore exceeded 250 to 1 [230].

Benefit-cost ratios in business are far from reaching the level of the first Courtauld Commitment, but according to the same report companies still obtain favourable ratios. In the cases of nearly 1200 business sites across 17 countries and more than 700 companies, from food-manufacturing and retail to food service, 99% of the sites achieved a positive return on investment. The median benefit-cost ratio was 14:1, signifying that half of the business sites achieved greater than a 14-fold financial return on investment.

Some interventions, such as nudging, are reported as being particularly cost-effective. The question of who benefits from financial savings can be an important one, especially when those who fund the intervention are not those who achieve the return. Lastly, data for calculating benefit-cost ratios are not easily available, and a possible bias exists in favour of publishing cost-benefit studies showing positive results resulting in an over-optimistic view of the net benefits of food-waste reduction interventions.

4.5 Towards versatile and multidimensional food-waste interventions

This chapter has provided an overview of the diversity of actors and actor constellations pushing the food-waste agenda, as well as the broad variety of instruments and initiatives they make use of in addressing food-waste reductions. It shows that there are many different approaches already in place or under development to address the reduction of food waste. Some of these can act as exemplary lessons that governments, industry and civil-society actors around the world can be inspired by when designing their food-waste reduction initiatives.

The main take-away points can be summarised following the main building blocks of food-waste interventions illustrated in Figure 4.1: actors and partnerships, the mix of instruments used, and the role of technology in enabling and accelerating interventions and outcomes in relation to the food-waste hierarchy.

Regarding actors and partnerships, governments, businesses and civil society all play important roles in reducing food waste from the local to the international levels. Governments are crucial in setting targets and, through regulation and taxes, creating incentives for businesses, households and individuals to change their behaviour. Different types of businesses, including food processors, distributors, retailers and food-service providers, as well as new technology providers, play a decisive role in influencing consumers' food-waste behaviour. And grassroots initiatives have proved to be successful in changing people's everyday practices related to food-waste behaviour. Building strong partnerships across public, private and civil-society actors tends to be better at making targeted interventions that address multiple levels and achieve large-scale effects.

4. ACTORS, POLICIES AND INSTRUMENTS IN FOOD-WASTE REDUCTION INITIATIVES

When it comes to policy instruments, it is clear that there is no one-size-fits-all approach, nor any one type of instrument that can address the complex issue of food waste. On the contrary, it is necessary to use a mix of instruments in addressing even just a part of the food-waste problem. Likewise, top-down and bottom-up approaches must be seen as complementary. On the one hand, top-down approaches, such as public-private partnerships and large awareness-raising campaigns, increase the notoriety and awareness of the issue on a large scale and are important for stakeholder mobilization. Regulatory tools, which are top-down by nature, stimulate waste-reducing practices (economic incentives, labelling) or reprimand waste-generating ones.

On the other hand, bottom-up approaches such as grassroots initiatives are useful for the uptake and dissemination of new everyday practices that lead to less food being wasted. Such initiatives are more efficient when they are designed within and by local communities, as they allow for concrete action close to the consumers. In a university canteen, for example, combining an educational campaign with different activities, prompts, supplies of paper bags for leftovers, social-media activity etc. addresses several factors at the level of individuals (awareness, attitude etc.) and at the level where behaviour takes place (the canteen setting), increasing the potential to be effective [206,208].

Green and digital technologies can widen the playing field of food-waste reduction initiatives and boost outcomes with respect to the food-waste hierarchy. New or already known technological solutions can enable and accelerate the interventions and efforts aimed at food-waste reduction. As a consequence, it is important to incorporate knowledge about technological solutions in initiatives to address food waste. For example, in developing countries, where the cold chain is inadequate or broken, governments, industry actors and grassroots organisations need to pool their efforts to implement off-grid small-scale refrigeration technologies in order to address food waste at the consumption stage. Another example is the integration of emerging IoT solutions in the catering and food-service sector. By placing small IoT scales under each plate and compost bins, food-service providers have access to new and precise data on food waste, which can improve their menu planning and thereby reduce food waste by up to 70% (see Box 4.2).

5. COMPARATIVE ANALYSIS OF FIVE CITIES

Cities and urban areas are becoming hotspots of food waste in both developed and developing countries. In 2008, for the first time in human history, more people lived in cities than in rural areas. Today, 4.2 billion people live in metropolitan areas, with numbers expected to grow even more in the future. This rapid and large-scale urbanization impacts on the environment. City-dwellers require vast quantities of food to satisfy their needs. Fulfilling this need generates large amounts of food waste, leading to growing impacts on the environment and climate. In Kampala, for example, 28% of city-wide emissions come from landfills, waste incineration and solid waste management together, making the waste sector the second biggest contributor of greenhouse gas emissions after energy generation [231].

Cities are also well positioned to pilot innovative solutions to food waste. The high density and close connections of social actors in urban areas, including government, civil society, industries and entrepreneurs, create huge opportunities for partnerships and innovations. Some of these initiatives include small-scale actors fighting food waste together. Others involve large private-public collaborations, partnering with international finance institutions and government bodies, as seen in the case of the upgraded Vinča landfill in Belgrade (Box 4.8).

This chapter focuses on five cities (Bangkok, Belgrade, Bogotá, Doha and Kampala) to explore how they are tackling the food-waste challenge using green and digital technologies in different national contexts and from different starting points. They provide a snapshot of the varying state of food waste and of perspectives on regional challenges and opportunities for tackling the issue. The city examples showcase how different actors, partnerships, technologies and instruments can be mobilized or adopted to address food waste. Annex 1 presents examples of food-waste interventions in the five cities. Summaries of each city case study can be accessed through the UNEP project website [232].

5.1 State and causes of consumer food waste

The per capita amount of food waste in each of the five cities varies significantly, though all five have witnessed a growing trend in food-waste generation in recent years. In Kampala, per capita food waste ranges from 0.24 to 0.47 kg per day, while in Bangkok it has risen 69%, from 0.36 kg per day in 2003 to 0.61 kg per day in 2018 [18]. The average resident of Doha generates close to 1.3 kg of domestic waste, almost twice as much. In Bogotá, it is estimated that 1,228,000 tons of food are wasted each year, of which 29,000 tons consist of dairy products and 590,000 tons of fruit and vegetables [233]. City-level data on food waste is not available for Belgrade, but national-level data for Serbia indicates that every person produces more than 35 kg of food waste annually, consisting mainly of bread, meat and dairy residues. Most of the data presented here are rough estimates made by researchers. There are no official data on food waste for the five cities that use the same methodology, making comparison across the cities difficult.

5.1.1 DIVERSITY IN PATTERNS AND FACTORS OF FOOD WASTE

As Chapter 1 showed, per-capita food waste does not vary systematically between countries in different income groups, implying that cities with quite different wealth statuses may experience comparable levels of food waste.

However, the composition of the food waste and the factors responsible for its generation may still vary significantly between cities. This is because of differences in local food systems and socio-economic conditions and because food waste is often the result of the interaction of multiple factors (see Chapter 2). These patterns and factors should be carefully considered in city-level food-waste interventions. In Kampala, for instance, large amounts of food are wasted at the retail and wholesale stages during the main harvest seasons, when large quantities of food flood the city's food markets, causing supply to heavily exceed demand. At the same time, local storage, processing and transport facilities are insufficient to preserve and store the food for later consumption or to export it to other areas, causing large amounts of waste. Furthermore, food is lost due to road damage, malfunctioning transport vehicles, inadequate cold-chain management and power outages. These food losses are particularly severe, as they put further pressure on local populations that are already experiencing food security-related challenges.

In the high-income city of Doha, large amounts of food waste are created by the tourism sector, by large buffets in restaurants and by households due to inadequate food planning. There is also a high risk of food damage in import procedures, which can take up to 12-24 hours to clear food. In Kampala, studies show that organic waste forms over 90% of total solid waste, 73% of which is vegetable matter that is largely food waste, both edible and inedible. In Bangkok, already high national food-waste patterns are amplified by an urban culture of consuming easy-to-access and ready-made food and snacks, especially among the younger generation, whereby people have come to expect that food is available at any hour of the day.

5.1.2 DIVERSITY IN SOCIO-ECONOMIC CONDITIONS AND FOOD SECURITY

Furthermore, food-waste assessments by cities should consider the fact that urban areas show a great diversity in cultural preferences and in social and economic status and conditions. Cities in low-income and middle-income countries in particular have a very varied food culture and food supply, with great inequalities in accessing sufficient amounts of nutritious food by both households and individuals. Food poverty is widespread here, meaning that many people are malnourished and/or rely on the redistribution of food via social networks or organizations such as food banks. In Kampala, for instance, 20% of the population experience food poverty. Hence, while all the cities presented in this chapter generate large amounts of food waste, some also exhibit significant levels of food insecurity.

Most food waste occurs at the final stages of the food-supply chain. Factors that influence this waste are diverse and differ from region to region. While some areas a challenged by infrastructure and malfunctioning logistics, others suffer policy and legal constraints. Photo credit: Kampala Case Study

5.1.3 DOMINANCE OF THE INFORMAL SECTOR IN FOOD PROVISION AND WASTE HANDLING

People in urban areas can access a wide range of localities that supply them with food. In many low- and middle-income areas, people typically obtain their food in local markets rather than from supermarkets. In Kampala, 88% of the households purchase their food from local markets. Local food markets also occupy crucial roles in Bogotá and Bangkok. For example, in Bangkok, there are more than 400 local markets. At the same time, modern trade has rapidly expanded and penetrated all income groups. A recent shift from a large hypermarket model to smaller, local convenient stores has been observed. In the context of COVID-19, online food service is also becoming more popular. Like most parts of the food system, the food markets in many cities in low- and middle-income countries operate within the informal sector. The latter also plays an important role in municipal solid waste management, including food waste. For example, around 3,000 people are employed in the informal provision of municipal solid-waste services in Kampala [231].

5.1.4 LACK OF WASTE INFRASTRUCTURE

The management of food waste in the five cities generally occupies a very low rank in the waste hierarchy; at the same time, most cities are increasingly concerned about the problems caused by inadequate management. One of the major challenges identified in the case studies is poor or inadequate waste infrastructure, including that related to waste collection, segregation and management (composting, recycling). In Bangkok, Belgrade and Bogotá, the vast majority of organic waste is delivered to landfills, creating adverse environmental effects while missing out on the economic benefits that green technologies could have provided. However, a gradual shift away from landfill practices towards incineration and anaerobic digestion (biogas) can be observed. Belgrade and Bogotá are currently investigating the opportunities of waste-to-energy facilities, while Bangkok and Doha already have such infrastructure in place to handle part of their waste. The incineration system in Bangkok processes 500 tons of waste a day and has an electricity-generating capacity of 5 megawatt. The city aims to increase this figure to 3,500 tons per day by 2032.

5.1.5 DATA CONSTRAINTS

Data inadequacies often limit the ability to acquire a clear picture of the state of food waste in a particular area or city. In many countries, waste data is only available nationally, not for cities or municipalities.

In most of the cities presented in this study, food waste is not measured as a separate category but is considered to be part of organic waste. As a result, there is a lack of data that compromises elaborate insights being obtained into the current food-waste situation in the respective urban areas. Bangkok, for instance, currently does not have a fully systematic food-waste management system in place. This further complicates obtaining an overview of current food-waste patterns, which are needed if relevant activities are to be developed and their successes benchmarked. However, the city authorities are gathering more general data on municipal solid waste. According to their figures, food waste accounts for up to 50% of the overall 3.47 million tons of annual waste. Similar food-waste ratios can be seen in Bogotá and Doha.

5.2 Policy and regulatory instruments

Many cities have introduced actions against food waste. The broad range of measures and approaches involved in these efforts are well illustrated by the five city case studies (see also Annex 1).

Belgrade, Bogotá and Doha strive to couple food-waste reduction efforts with sustainable development practices. They have formulated and implemented ambitious waste-prevention and recycling/recovery policies based on circularity principles, which has led to significant reductions in per-capita waste generation and higher recycling rates, as well as financial benefits.

All five cities either have waste policies in place or are currently developing them, but only in Bangkok, Belgrade and Bogotá do these policies and support programmes directly or explicitly address food waste. All three cities combine long-term plans with short-term activities that yield fast results and experiences.

The city of Bangkok, for instance, has developed a long-term plan to promote and preserve environmental quality, covering a period of almost 20 years up to 2036. The plan includes the development of data-collection platforms that enables the city to benchmark and measure achievements and impacts related to food waste. This is important because the lack of reliable data and data systems in Bangkok and other cities in Thailand constrains the development of impactful actions to reduce waste. In addition, the city of Bangkok has launched several short-term initiatives to promote and enable the engagement of civil society and public-private partnerships in reducing food waste. The plan and initiatives are part of a wider national policy to tackle waste issues and to promote environmental protection. It recognizes the vital role that cities play in reducing waste, including food waste, and also identifies cities as the main source of waste. The policy therefore seeks to increase the capacity and competencies of local authorities to address and manage the waste issue more effectively.

Similar developments can be seen in Colombia, where Bogotá City Council has established guidelines to increase food-waste prevention by means of awareness-raising, training campaigns, promoting citizen responsibility initiatives, promoting strategies that allow the reuse of potentially edible food for animal consumption, and establishing mechanisms and strategies to coordinate food-waste reduction efforts. See Box 5.1. Like Bangkok, the local authorities in Bogotá aim at enabling private-sector engagement by providing clear guidelines and frameworks.

Finally, in Uganda refrigerated trucks are being promoted through import-tax exemptions, thereby providing policy support to cold-chain development. However, while such trucks are widely used for long-distance transportation, e.g. of fish for export markets, they are seldom used in the final stages of the food supply chain, which accounts for a large share of the country's food loss and waste.

Hence, while strong policies, including programmes and clear regulations, are crucial in enabling food-waste reduction and engaging all relevant actors in waste-reduction initiatives, only two out of the five cities analyzed addressed the particular issue of food waste in their waste-policy initiatives.

Box 5.1. Policy coordination mechanisms for food-waste reductions in Bogotá

Bogotá's District Council for Economic Development coordinates the Intersectoral Commission of Food and Nutritional Security or CISAN Bogotá (its acronym in Spanish). This Commission is responsible, among other things, for:

- Establishing mechanisms and strategies for coordination and communication among all actors involved in the food value chain (including production, supply and consumption) and the value network directly related to the food sector in both the public and private sectors, in order to prevent food loss and waste within the Capital District.
- Promoting institutional actions for the dissemination of 'good practices for food producers, processors, distributors and marketers in the city' as well as 'good purchasing habits and responsible consumption', targeting consumers.

Source: UNEP Regional Office for Latin America and the Caribbean and [234].

The Paloquemao market square in Bogotá. Photo credit: Shutterstock

5.2.1 POLICY INCENTIVES AND PERVERSE EFFECTS

The city case studies revealed a limited use of policy incentives (e.g. taxation, tax rebates, subsidies, fines) to encourage key actors to reduce food waste. They also pointed to the need to remove incentives that have the perverse effects of preventing or discouraging actions to reduce food waste. The Kampala study showed that waste policies in Uganda provide tax rebates to manufacturers that use certain packaging materials. However, the rebate is only available to vendors who plan to export their goods, so the environmental benefits will accrue to the importing countries, with no effect on local food waste.

Several cities also identified the challenges posed by food-safety regulations, which made supermarkets, charities and private-sector actors reluctant to participate in food-donation programmes, thus limiting the opportunities for partnerships and initiatives on food redistribution. A particular concern is that donating partners may be held responsible for people falling sick from the redistributed food.

The above example illustrates the point made in Chapter 4, namely that policies often set the boundaries within which food-waste partnerships can operate, thereby enabling or limiting (as in this case) waste prevention or recycling.

5.3 Partnerships and initiatives seeking to reduce food waste

5.3.1 INITIATIVES TARGETING LOCAL FOOD MARKETS

The locations where people purchase their food also determine the different types of partnership that are established, as well as the focus areas these partnerships target. In Bangkok, Belgrade, Bogotá and Kampala, many consumers buy their groceries at local food markets, rather than in grocery shops and supermarkets. Accordingly, these cities host partnerships and initiatives that are led by or at least include these actors. Here, improved management of market facilities is one of the foci of these initiatives. In Bangkok, for example, the city government supports micro-scale initiatives and engages with different local communities and other stakeholders to promote the reduction of food waste. It actively supports community-driven grassroots initiatives, but does not intervene directly itself in food-waste activities. The projects created through these partnerships include joint food-waste collection, waste-recycling and food-waste reductions in local markets.

In Kampala, the city government has been integrating urban farming into its urban-planning framework to curb food losses from long-distance transportation. Furthermore, in collaboration with the company Marula Protein, the municipality is piloting a project that addresses sustainable waste management by creating a high-quality protein feed for livestock. The city collects organic waste from local food markets, which is later fed to Black Soldier Fly larvae with the purpose of harvesting the insects and processing them into protein feed.

5.3.2 INITIATIVES TARGETING COLLABORATIVE CONSUMPTION

Collaborative consumption at religious, cultural or social events can generate large surpluses of food, as noted in Chapter 4. During the month of Ramadan, for instance, research indicates that between 25% and 50% of the food prepared for religious gatherings is wasted, and similar patterns have been observed at other events, such as Christmas and wedding parties. Several initiatives and partnerships have emerged that aim to reduce food waste in this context. In the city of Doha, the business start-up Wa´hab addresses this issue and creates new partnerships with retailers, restaurants and event-management agencies, such as the Qatar International Food Festival. The aim is to reduce food waste by rescuing surplus food and redistributing it to people in need. At the same time, Wa´hab and its partners have developed awareness-raising campaigns that bridge the gap between the cultural, ethical and environmental dimensions of food waste.

The Sustainable Ramadan Campaign launched by UNEP West Asia in 2021. Photo credit: UNEP

5.3.3 FOOD BANKS

A well-established type of initiative present in all the five cities is the systematic redistribution of surplus food through so-called food banks (see Chapter 3). Food banks are trending on a global scale, being institutional arrangements that enable and organize the collection of surplus food from different food-system actors (agro industry, retailers, restaurants, food services companies etc.) and re-distribute it to vulnerable social groups.

The food bank in Belgrade, for instance, works in cooperation with more than 200 social institutions and organizations. Furthermore, the city's food-bank network recently engaged in a collaboration with UNDP in Serbia. UNDP Serbia Tech Cell provides technology support in developing a digital platform connecting over a hundred retailers with charitable organizations and initiatives, improving efficiency in food redistribution, and ultimately minimizing food waste. Retailers register food surpluses and food donations through the 'Plate by Plate' platform, data that are then made available to humanitarian organizations. Consequently, they can reserve and later collect the donations and redistribute them to those in need.

5.3.4 INITIATIVES TARGETING FOOD SERVICES

The city case studies also revealed initiatives addressing food waste in the food-service industry, similar to those described in Chapter 4. This is also a place where green and digital technologies have shown their growing potential to make a real difference. Technologies such as mobile apps, QR code-based applications, smart compost bins and data-analysis tools have been piloted in hotels, restaurants and university campuses. Box 5.1. presents an example from university canteens in Bangkok, which targets the whole waste cycle, from prevention to recycling.

Box 5.2. Reducing food waste in canteens: the Chula Zero Waste Initiative in Bangkok

Chulalongkorn University in Bangkok, Thailand, led the 'Chula Zero Waste' initiative to reduce food waste from its 17 canteens from 2017 to 2021. It targeted the entire waste-management cycle and included awareness-raising activities for both food-waste prevention and separation, upgrading of the waste separation system (with newly designed bins and labels to increase communication), data-collection tools and exercises, training for canteen staff, and a clear strategy for addressing food disposal.

The initiative has achieved positive results. In the 17 canteens, consumer food waste fell from 1,738 kg/day in 2016 to 1,011 kg/day in 2019. Of the 1,011 kg, only 1% (8 kg) was left to be managed by the Bangkok local government, while 98% (993 kg) was utilized as animal feed, and the remaining 1% (10 kg) was fed into a biodigester, which can convert wasted food into compost and bio-fermented water. Food waste from vendors decreased from around 1,200 kg/day in 2016 to 576 kg/day in 2019. Source: The Food Waste in Bangkok workshop, organized by UNEP on 20 May 2021 [235].

Photo credit: Chulalongkorn University

5.3.5 PARTNERSHIPS TO DEVELOP BETTER FOOD-WASTE POLICIES

As highlighted in Chapter 4, actors can work in many different set-ups deploying a variety of instruments to reduce food waste. In Belgrade, a group of organizations has established a partnership working in collaboration with the Serbian government and the Chamber of Commerce on improving legislation and other legal frameworks that regulate food waste in the country. Here, the target is to influence policy in a way that further incentivizes organizations to donate food surpluses, e.g. in the form of tax reductions on donated goods etc.

A similar partnership that connects a broad network of actors that jointly seek to influence policy and fight food waste is the #SinDesperdicio initiative targeting food loss and waste in Latin America and the Caribbean. It was founded in 2018 as an initiative of the Inter-American Development Bank (IDB), and 12 additional corporate, knowledge and advisory partners have since joined it, including Coca Cola, Dow Chemicals, the FAO, the Global Food Banking Network, Nestlé and WRI. Besides advocating and promoting food-waste policy and regulations, the partnership has introduced hands-on initiatives in several Latin American cities. In Bogotá, for example, #SinDesperdicio created contests to come up with creative solutions to existing food-waste challenges. The supported initiatives include start-ups developing simple techniques that extend the storage life of fruits and vegetables, and developers of smartphone applications that connect vendors with logistics companies to enable the reliable and safe transport of food at low cost.

5.4 Opportunities created by green and digital technologies

Green and digital technologies play an important role in the food-waste initiatives in all five cities, including some of the technologies analyzed in Chapter 3, namely technologies for food-sharing, food preservation, packaging, storage, recycling and recovery.

5.4.1 GREEN TECHNOLOGIES

Several of the green technologies identified in the city case studies were relatively simple, while still yielding important economic and environmental benefits, and often providing solutions to a multitude of problems. Some highlights are presented here.

In Kampala, many market actors use airtight (hermetic) double-layer bags for grain storage and transport. This packaging technology kills pests and protects the grains against physical damage, thereby extending the shelf life of the grains while ensuring their quality.

In Bangkok, local market operators have created a reward system that encourages vendors to collect and return their organic waste. As part of the market's waste-management initiative, vendors return their food waste to the market management. The residues are then disposed of in the market's own biogas facility. In addition, part of the food waste returned by vendors is gathered to create bio-fermented water. Here, food waste and organic waste are mixed with water and sugar and left to ferment. Fermentation is a type of biotechnology that uses organic material in combination with microorganisms to create chemical change that can produce fertilizers as well as insect repellant. In Thailand, this is a commonly used feature, with many local markets offering similar projects throughout the country.

A similar technology is being promoted in Doha, where an NGO is encouraging the use of domestic composting devices to improve the recycling of household food waste. Other small-scale technological innovations are being promoted in Qatar's capital, ranging from artificial intelligence to simple mobile applications. Doha's technology sector is currently ramping up its efforts to reduce food waste significantly. When advertising and promoting these solutions, the city can rely on its high degree of digitalization and social network users to accelerate diffusion among customers and users.

The development and diffusion of green technologies addressing food waste is not only limited to civil society and the private sector. In Kampala, the municipal government has a partnership with the Ministry of Energy and Mineral Development to assess the potential of biogas technology to improve the city's overall energy supply. Increasing efforts to investigate the potentials of biogas, incineration and recycling facilities can be seen in Bangkok, Belgrade, Bogotá and Doha, underlining the growing awareness of the full potential of improved waste management through the deployment of green technology.

5.4.2 DIGITAL TECHNOLOGIES

Many green technologies being implemented in today's cities make use of digitalization. In many areas, food markets and retailers embrace digital innovations and technologies by making use of smart devices to connect with their customers and partners.

The use of digital tools in the cities is particularly prominent in food-sharing schemes, which are on the rise globally, as seen in Chapter 4. The schemes connect vendors, retailers, restaurants, manufacturers etc. that generate a food surplus with food-donation organizations and end-users. Enabled by data platforms and smartphone apps, they seek to minimize food waste by reducing the inconvenience, costs and delays in redirecting surplus food to those in need. In Bangkok, for instance, local market retailers have created a reward system that encourages vendors to separate their food waste by issuing 'coupons'. Vendors can give these coupons to customers, who can then use them to buy various green products. Box 5.3 presents more prominent examples.

Box 5.3. Food-sharing schemes enabled by digital technologies in Bangkok, Belgrade and Bogotá.

In **Bangkok,** the anti-food waste start-up company Yindii uses digital technology to connect surplus food providers with consumers. Through its mobile app, launched in 2020, individuals can purchase surplus food from restaurants across the city and choose to pick up their orders or have them delivered to their home [236].

Yindii food sharing start-up in Thailand. Photo credit: Yindii

In **Belgrade,** the web-based platform FoodSHare was launched in 2021 by the Foodscale hub [237]. It connects food donors, recipients and volunteers to reduce food waste, aiming to streamline surplus food donations to socially disadvantaged groups by facilitating communication and logistic processes. Donors in the form of shops, restaurants, hotels, and public institutions like hospitals and universities can post donations on both a regular and a one-time basis and can choose from an array of FoodSHare's recipients. Matches are based on donors' and recipient organizations' profiles, including the type and quantity of food they donate or need, their proximity and timing.

In **Bogotá,** a similar application connects food manufacturers and retailers with food banks. Making use of digitalization and artificial intelligence, the EatCloud platform identifies the places and moments when food is being wasted throughout the supply chain. As vendors provide real-time data to the platform, measures can be taken before the food is thrown away. Fed with data from the food suppliers and using AI, the platform automatically chooses the ideal beneficiary for each kind of food waste. Since its creation, the data shared through EatCloud has provided more than 34 million meals for people in need.

Redistributing fruits and vegetables in Bogotá during the pandemic. Photo credit: EatCloud

5.5 From food-waste hotspots to innovation hubs

As indicated by the five city examples presented in this study, food waste is becoming an urgent environmental, social and economic problem that needs to be addressed. Food waste in all five cities has witnessed an increasing trend over the past years, resulting in mounting pressures on the environment.

Cities also show diversity in the patterns, drivers and factors influencing consumer food waste, including socio-economic circumstances, the food-security situation and various development statuses in respect of food consumption and supply chains. Positive progress has been made in improving policy frameworks, upgrading waste infrastructure, supporting green-tech based business models, and fostering partnerships across different sectors. Yet some common challenges remain to be addressed if cities are to be transformed into future innovation hubs for action on food waste.

First of all, so far none of the cities has an official data system to measure consumer food waste and track progress in achieving food waste-related SDG targets. Most of the data come from rough estimates based on municipal solid waste, biodegradable waste, or organic waste. There is an urgent need to fill in the gap in data collection and analysis.

Secondly, although all five cities have put forward policies on food waste at either the national or municipal levels, there is a great deal of room for improving implementation and effectiveness. In order to establish accountability and transparency throughout the food supply chain, more enforceable policies are needed. Binding regulatory frameworks, mandatory standards and waste-management systems could provide clear guidelines and incentives to key actors. Efforts should also be made to remove perverse incentives that prevent actions to reduce food waste.

Thirdly, while multinational companies and big retailers have become more active in introducing measures to reduce food waste, their initiatives are often based on self-reporting and voluntary commitments. This makes it difficult to benchmark their efforts and to measure their impacts. Furthermore, many of the activities undertaken by large companies and retailers focus more on reuse and recycling and less on preventing food waste. This also applies to initiatives that seek to shape and reformulate policies and that strive to ease legislation on taxation and expiration dates, rather than addressing food over-production and prevention measures. At the same time, small and medium-sized enterprises (SMEs) are still hesitant to follow suit due to concerns over the cost and resources needed to change practices.

Finally, all five cities have identified an urgent need to raise consumer awareness of food waste and to provide more information and support to empower consumers to act on food-waste reduction. Social media campaigns and capacity-building programmes can be rolled out on larger scale to improve understanding of the link between food waste and the planetary crisis, and to share experience and good practices in changing behavior in the directions of less food waste and more sustainable food consumption.

6. CONCLUSION

Our research shows that, despite an increase in actions and awareness in past decades, food waste remains a big problem, with profound environmental, social and economic consequences. Food waste by consumers plays a big part in total food loss and waste along the food value chain. Cities in both developed and developing countries are becoming hotspots of consumer food waste, due to rapid urbanization and increased economic activity. This leads to growing pressure on the environment and calls for urgent actions from key players and stakeholders, including governments, industries, consumers and civil society.

There is a **big gap in data and assessment** of consumer food waste with respect to its quantity, quality and sources, but also regarding its associated costs, its social and environmental impacts and future projections of waste types and amounts. Data at the city level is even scarcer, as seen from the five city case studies. Most of the data on consumer food waste was based on rough estimates that were not accurate or comparable. This calls for more efforts to systematically measure and assess consumer food waste. The Food Waste Index Report launched by UNEP in 2021 provides a common methodology for measuring food waste and tracking progress on SDG 12.3. The Food Loss and Waste Accounting and Reporting Standard (or FLW Standard), published in 2016 [175], is also expected to provide more guidance on quantifying and reporting on food waste. Countries and cities can use these tools to build their data systems to measure and analyse food waste.

Both academic research and the city case studies point to **complex causes** that drive consumer food waste. The food-waste hierarchy illustrates priority areas, starting from prevention to re-use and recycling. Our research shows that the causal mechanisms and factors influencing food waste at the consumption stage are manifold and complex. Consumer food waste therefore cannot be attributed to single variables. Instead, it needs to be understood and addressed by considering the inter-connections between groups of factors, such as attitudes, knowledge, skills, values, gender, income and living standards, and social and cultural practices, as well as food-system factors (markets, prices, infrastructure etc.).

The use of **green and digital technologies** is opening up new opportunities to raise awareness, change perceptions and drive changes in consumer behaviour towards less food waste. Examples from the five cities and in countries such as Denmark, the UK and the US demonstrate the growing uptake of green and digital technologies to prevent, reduce and recycle food waste. These include technologies related to food preservation, storage, packaging, labelling, pricing, traceability, redistribution, recycling, upcycling, food-sharing, meal-planning and food donations.

These innovations are encouraging and inspiring, yet most of them face the challenge of **upscaling** and going beyond the 'niche market'. While big companies are in a good position to engage with partners along the value chains, many SMEs and local business owners in developing countries have concerns over the cost and resources needed to deploy green and digital technologies to reduce food waste.

There is also a lack of data on the cost savings and environmental and social benefits of adopting such technologies. To fully unlock the potential of green and digital technologies to reduce consumer food waste, **an enabling environment** is needed that connects policy, regulation, infrastructure, consumer information, economic incentives, awareness-raising and behaviour nudges. There is also a need to **raise consumer awareness** of the food-waste crisis and drive the demand for green solutions to waste reduction and management.

Governments at both the national and municipal levels can establish systems to measure and manage food waste, track progress in achieving related SDG targets, and provide the right incentives and opportunities for changes in consumer behaviour and business practice. As shown by the five cities, policies and regulations need to combine long-term strategies and road-maps with short-term targets and concrete measures to ensure effective implementation. They also need to address the gaps in capacity and knowledge of different actors and engage with stakeholders in the food system and along the food value chain. Governments can also improve urban waste infrastructure to enable access to composting, recycling and other waste-management facilities. Public-private partnerships offer an effective model in securing investment, mobilizing resources and expertise in infrastructure development while minimizing the risks to businesses. They are increasingly being considered and used by developing countries.

Different types of **businesses,** including food-producers, distributors, retailers, food-service providers and technology providers, play an important role in coordinating efforts along the food supply chain and in influencing consumers' food-waste behaviour. Initiatives led by businesses and industries have taken the form of voluntary agreements between supply-chain operators, retailer-supplier contracts, joint communication and information-sharing programmes, and monitoring and traceability systems, among others. Some entrepreneurs and start-ups are also embracing circular business models in their food-waste innovations.

Grassroots initiatives led by local communities and individuals have proved to be successful in reshaping the everyday food consumption practices of individuals and households. They are driven by social and/or environmental goals and built around activities such as food-growing, food-rescuing and food-sharing.

Internationally, **global and regional networks and partnerships** have become important platforms for knowledge-sharing and capacity-building by governments and other stakeholders in the food system. These networks help make the huge challenges of food waste visible through their activities and develop and diffuse knowledge across the world.

Moving forward, **strong partnerships** between public, private and civil-society actors locally, nationally and internationally tend to be better at making targeted interventions that address multiple levels and at achieving large-scale effects to reduce food waste. It is also recommended to use a mix of instruments, such as policy, regulation, economic incentives, consumer information, awareness-raising activities and behavioural nudges.

More **research** can nonetheless be conducted to examine how top-down and bottom-up approaches can complement each other in achieving the expected results and achieving buy-in from key players across different sectors. More hands-on experience could also be collected and analysed on how to tailor food-waste interventions to local circumstances and account for different social and cultural factors, such as gender, food security and equality. In-depth case studies of successful business models and social innovations could also provide valuable insights in facilitating the design and implementation of food-waste interventions.

ANNEX 1. EXAMPLES OF FOOD-WASTE INTERVENTIONS IN FIVE CITIES

BANGKOK

Category by key actors	Intervention	Instruments or technologies
Government (national)	Policy and Plan to Promote and Preserve the National Environmental Quality (2017-2036).	Policy
	Environmental Quality Management Plan (2017- 2022).	Policy
	Sustainable Production and Consumption Plan (2017-2037).	Policy
	Draft Action Plan (2021-2027) for Thailand's development of a Bio-Circular-Green Economic Model (BCG).	Policy
Government (municipal)	Bangkok's 20-year Waste Management Strategy.	Policy
	Community-based programmes for information-sharing and pilot projects.	Capacity support Awareness
Private sector	Yindii mobile phone app to connect surplus food providers with consumers	Digital technology
	Wastegetable and Bangkok Rooftop Farming collaborate to form a closed-loop business model that collects and converts food waste into compost for urban farming.	Circular economy

BELGRADE

Category by key actors	Intervention	Instruments or technologies
Government (national)	Law on Waste Management	Legislation
Government (municipal)	2021-2030 Plan for Waste Management for the City of Belgrade.	Policy
Private sector	Web-based platform FoodSHare connects food donors, recipients and volunteers to reduce food waste.	Digital technology
	'Plate by plate' uses blockchain technology to connect Ahold Delhaize stores (the biggest food re-tailer in Serbia) with social and humanitarian institutions that cooperate directly with food banks.	Digital technology
Civil society	Food Bank Belgrade.	Information Awareness
	The project 'Towards better food waste management in the Republic of Serbia' (led by GIZ) has worked to improve the framework for the collection and recycling of food waste.	Knowledge and advocacy
Public-private partnership	Through a partnership with the International Finance Corporation, the Rockefeller Foundation and several governments, the Vinča landfill in Belgrade, the largest unmanaged open dump in Europe, is being transformed into a new waste facility, including a new sanitary landfill, a waste-to-energy plant and a construction-waste recycling unit.	Green technology Infrastructure

BOGOTÁ

Category by key actors	Intervention	Instruments or technologies
Government (national)	Law 1990 / 2019.	Legislation
	National Circular Economy Strategy.	Policy
Government (municipal)	Agreement 753 of 2019 (Bogota).	Policy
Public-private partnership	The #SinDesperdicio platform to fight food loss and waste is a pioneering initiative supported by the Inter-American Development Bank (IDB) and including 11 food multinationals, NGOs and international organizations.	Information Awareness
	The Reagro Program led by Fundación Saciar and co-funded by Grupo Éxito, through which perishable food is directed to composting processes.	Information Awareness
	The Buen Provecho Initiative of Alpina, which seeks to optimize food-handling together with producers, among others.	Information Awareness Capacity support

DOHA

Category by key actors	Intervention	Instruments or technologies
Government (national)	The Second National Development Strategy (2018- 2022).	Policy
	Government (municipal)	Infrastructure Green technology
Government (municipal)	Nationwide initiative at Al Khor Park to turn food waste and tree leaves into organic fertilizer through a recycling machine.	Green technology
Private sector	Wahab, a business start-up based in Doha, collects – with the help of volunteers and partners – excess food, packages it and delivers it to beneficiaries.	Information Awareness
Civil society	The Qatar Foundation promotes food-waste prevention and reduction through its Education City campus initiative, food-services group, webinars and other events.	Information Awa-reness Capacity support
Public-private partnership	The Sustainability Club at Georgetown University in Qatar has been tackling the challenge of food waste by introducing its campus community to 'upcycling' through a collaboration with Qatar Upcycling & Biodegradables Enterprise.	Green technology

ANNEX 1. EXAMPLES OF FOOD-WASTE INTERVENTIONS IN FIVE CITIES

KAMPALA

Category by key actors	Intervention	Instruments or technologies
Government (national)	Uganda Vision 2040 overarching development plan.	Policy
	Nation Development Plan III (NDP III).	Policy
	Agriculture Sector Plan (2015/16-2019/20).	Policy Financial support
	Global Food Security Strategy (GFSS) Uganda Country Plan (2018).	Policy
	5th Schedule of the East African Community Customs Management Act (2004).	Policy Economic incentives
	Environment Management Act (2019).	Legislation
Government (municipal)	Kampala Capital City Authority (KCCA) Strategic Plan (2020).	Policy
Public-private partnership	Collects food waste from markets and feeds it to Black Soldier Fly larvae to produce high-quality protein for animal feed (KCCA and a company, PROTEEN (U) Ltd.)	Green technology
	Pilot project to separate food waste at the Usafi Market in Kampala, where food waste is collected in different bins and sold as animal feed (KAAC).	Green technology
	Farm to Plate Virtual Market (K-Smart Market, a digital mobile phone application) to facilitate urban farmers and food vendors in selling directly to consumers.	Digital technology
Private sector	The Fruiti-Cycle company has designed an electric tricycle with a refrigerated storage unit, which uses an evaporative cooling system that is solar-powered to prolong the shelf life of fresh produce during distribution.	Green technology
	Sparky Dryer, an eco-friendly dehydrator built with steel and wood, runs on biofuel and burns with zero-carbon emissions to dry fruit, vegetables, cereals and grains.	Green technology

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