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Household Food Waste as Animal Feed – an Analysis and Evaluation

Háztartási élelmiszerhulladék állati takarmányként – Elemzés és értékelés

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Abstract

Food waste is a serious global concern, both in its production and its disposal. This thesis aims to evaluate and analyse possible solutions to this challenge. Circular economy cycles were drawn up for the revalorisation of food waste through composting, anaerobic digestion, and the production of animal feed. Special attention was paid to the revalorisation of food waste into animal feed especially for poultry and swine and through the use of insects. A reference was made to the techniques and successes demonstrated by South Korea.

This thesis also highlights findings derived from a research study, which through the application of the FUSIONS methodology, measured food waste generated in Hungary at a household level. I contributed to this study alongside the research team, by fielding questions and subsequently analysing data. Insights were gained regarding the average amounts and types of food waste generated, along with the reasons precipitating the food waste and the methods of disposal.

It was concluded that a significant amount of the generated waste (15.4%) of all the generated waste was fed to animals (pet and food animals around the household). Based on my subsequent theoretical calculation, the average Hungarian household could feed their generated food waste to one or two hens (potentially up to 3.25, assuming an optimistic scenario), which would then account for a substantial portion of their egg consumption.

Absztrakt

Az élelmiszerhulladék globális szinten komoly terhet jelent, mind a keletkezése, mind pedig az megsemmisítése tekintetében. A dolgozat célja e kihívás lehetséges megoldásainak értékelése és elemzése. A munka ennek megfelelően foglalkozik a körforgásos gazdaság kérdéseivel és az élelmiszerhulladék újrahasznosításával komposztálás, anaerob lebontás és állati takarmány előállítása révén. Különös figyelmet kapott az élelmiszerhulladék állati takarmányként történő újrahasznosítása, különösen baromfi, sertés és rovarok esetében, szembe állítva az európai országok gyakorlatát a Dél-Korea által alkalmazott megoldásokkal.

A dolgozat bemutatja a magyar háztartási élelmiszerhulladék-mérést, amely a FUSIONS módszertannal készül. A kutatócsoport tagjaként hozzájárultam a kutatáshoz a kérdőív kialakításával és az adatok elemzésével. Az eredmények felölelik az átlagos mennyiségeket és élelmiszerhulladék-típusokat , valamint képet nyújtanak az élelmiszerhulladék keletkezésének okairól és az elhelyezési módszerekről.

A kutatás eredményeként megállapítást nyert, hogy a keletkezett élelmiszerhulladék szignifikáns része (15,4%) állati takarmányként hasznosul (társállat és élelmiszercélú állat egyaránt). Elméleti számításaim alapján a magyar háztartások átlagosan egy vagy két tojótyúkot tudnának eltartani az általuk termelt élelmiszerhulladékból (a legoptimistább forgatókönyv szerint akár 3,25-öt is), amely jelentős részt képviselne a tojásfogyasztásuk fedezésében.

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1. Introduction

Food waste is a global phenomenon with far-reaching repercussions. It is estimated that globally one-third of all food made for human consumption ends up as food waste, which is equivalent to approximately 1.3 billion tonnes of food [1].

This immense amount of waste is even more noteworthy when compared with the food security issues that the world is currently facing. The prevalence of undernourishment was 9.2% worldwide in 2022, equalling approximately 735 million undernourished people worldwide. Unfortunately, due to the recent COVID-19 pandemic and the Ukrainian War, projections concerning undernourishment are alarming, especially in African and Latin American countries, in forecasting higher increases than were previously considered. Furthermore, Food Insecurity levels are even more preoccupying, with 11.7% of the world suffering from severe food insecurity, with a staggering 29.6% facing moderate or severe food insecurity in 2022 [2]. These distressing statistics are even more problematic in view of the ever-increasing worldwide population. It is estimated that by 2050, the global population will hit the 9.7 billion mark [3]. Therefore it is essential that these alarming rates of undernourishment and food insecurity are stemmed without delay, with one such viable solution lying in the proper reduction, handling, and management of food waste. As Toine Timmermans points out: “To feed the world, we don’t need to produce more; we need to waste less” [4]. Also with current trends of urbanisations, more people are moving from rural farming areas to cities, which means that there are less and less farmers to produce food for an ever-increasing population [1].

As stated previously, it is estimated that circa 1.3 billion tonnes of food are wasted every year. It is conservatively estimated that globally, the amount of edible food thrown away every single day corresponds to approximately one billion wasted meals [5]. Such disturbing and consequential statistics attest to the necessity of properly reducing, managing, and controlling food waste. It is theoretically possible that with the proper redistribution of food waste, food security, and undernourishment rates could be significantly reduced. Moreover, theory apart, there are other, more tangible, and feasible manners in which the management of food waste could significantly have a positive impact on the aforementioned rates of undernourishment and food insecurity, and in a nutshell, this is what this thesis will concentrate on and delve into.

2. Literature review

2.1. Food Waste

There are many different definitions of food waste found in literature with the main distinction being the stages at which the food waste occurs. According to Gustavsson et al. (2011), Food waste is to be divided into food loss and food waste. Food loss pertains to a decrease in edible food during the production, harvesting, and processing stages while food waste concerns the edible food decrease during the retail and consumer stages. On the other hand, another definition states that Food Waste is the loss of edible food from any part of the food chain including the production, processing, retail, and consumer stages [6]. Notwithstanding the various interpretations, for the purpose of this thesis, the divergence of the definition does not have a significant impact since the thesis will focus on food waste during the later stages of the food cycle. However, it is important particularly where future studies and future legislation are concerned that a concordant definition be made so as to avoid confusion and hence better streamline information.

Food Waste can be divided into three categories: Avoidable Food Waste, Potentially Avoidable Food Waste, and Unavoidable Food Waste. Avoidable food waste encompasses edible food items needlessly discarded, including meals, baked goods, fresh produce, and animal products. Potentially avoidable food waste consists of foodstuffs that can be edible or inedible depending on personal preference and cooking methods, which include animal skins, vegetable/fruit peels, and bread crusts for example. Unavoidable food waste comprises inedible food that has never been and could never be edible, including bones, shells, tea bags, and non-consumable produce parts [7].

It has been estimated that a significant portion of food waste at the consumer stage is Avoidable Food Waste [8]. In different studies performed in Hungary, the percentage of Avoidable Food Waste was found to be 48.7% and 48.1% [9], [7]. Different studies in different countries showed varying amounts of avoidable food waste: 34% and 35% in Greece and Sweden respectively on the lower end and 56% in a Danish study [10] [11], [12]. It should be noted that different methodologies were used in the different studies: the Greek and Swedish studies did not include liquid food waste in their calculations and the Danish study only divided the categories of food waste as avoidable and unavoidable. These differing methodologies could account for the discrepancy in the results obtained. Irrespective of the different values at least

a third of all food wasted is avoidable. Applying this value to the total amount of food waste annually it could be extrapolated that there are 433 million tonnes of edible food thrown away yearly. This demonstrates the necessity to further investigate the reasons behind this occurrence so as to more effectively minimize it in the future.

When food waste is generated it needs to be then processed using waste management practices (WMP). Currently, in the EU, and in most developed countries, there are three major WMPs: landfilling, thermal conversion (incineration + gasification), and biological conversion (anaerobic digestion + composting) [13] [14]. These WMPs result in economic losses, and negative environmental impacts which will be discussed in section 2.1.2. [15].

2.2. Causes of Food Waste

In order to reduce the current substantial rates at which food is being disregarded, it is critical that the cause of food waste is determined. Globally the average amount of food wasted per capita per year amounts to more than 80kg [5]. In Europe, it is estimated that 53% of food waste occurs at the consumer stage [16]. Therefore, it is imperative that strategies need to be implemented to reduce this rate of wastage.

A multitude of studies have aimed to find the most common causes of food waste at the consumer level. One should note that there is not one specific reason for the wastage of food, but it is a multifaceted issue that includes socioeconomics, culture, environmental awareness, consumer behaviour, and multiple other factors.

Income is one factor that has been linked to the amount of food waste. A typical finding is that there is a correlation between income and food waste. The prevalent outcome is that higher income leads to more food waste at a consumer level, while in low-income areas it is more likely for food waste to occur at the production and harvesting stages [17] [18]. Despite this, it is important to not associate consumer food waste with high-income areas alone. In a study conducted in Brazil, Porpino et al (2015), found that lower-class families may also end up wasting significant amounts of food [19].

Table 1 summarizes the main findings related to increased waste loss and the reasons behind such waste.

Table 1: Factors leading to increased food waste generation.

Factors Increasing Rates of Food Waste	***Reason***	***Source***
Gender	Men have been observed to produce more food waste than women.	[9]
Urban residents	Urban residents are less likely to have access to a garden, making composting more difficult. It also relates to other factors such as household size and employment.	[9] [20] [21]
People living alone	Packaging sizes typically contain more than one serving which leads to over-purchasing.	[22]
Households with children	Children are pickier with food and are more likely to not finish their meal. Also links with large portion sizes as some studies observed that parents will often prepare too much food for their children.	[9] [23] [24] [19] [25] [26] [27]
Higher than average income	People with higher incomes are less likely to budget out how much money they can spend on food. They are also more likely to purchase perishable foods.	[9]
People under 60	People above the age of 60 typically generate less food waste. This has been associated with more knowledge and the “pre-war” mentality that result in an increased level of rationing.	[9] [28]
Employment	Employed people have been observed to produce more food waste. This can be linked to income rate and lack of time. It is more likely for employed people to end up buying pre-processed meals due to time constraints while not using already-bought produce.	[20] [22]
Lack of knowledge	Lack of knowledge about proper preparation and good storage techniques.	[29] [19]

Types of food	More perishable foods such as fruits, vegetables, and bakery products are the most frequently thrown-out foods.	[7] [22] [30]
Bad shopping habits	Unplanned shopping trips and no shopping lists increase the chance of impulse buying and buying more food than needed. Bulk shopping resulting from promotional offers also increases the rate of food waste.	[24] [31] [22] [19]
Bad food preparation and storage	Preparation of excess food, bad food storage, and ignoring leftovers have been linked with increased rates of food waste.	[31] [23] [21] [19]
Good Host or Good Provider Identity	This is more likely to increase food waste as people with this identity link the overproduction of food with showing their love or hosting abilities.	[22] [19]
Compensating effect	People who eat less healthy will often buy an increased amount of perishable items to minimize guilt. However, they do not eat the perishables and end up throwing them away.	[22]
Time constraint	Reduced time to cook results in an increased likelihood of purchasing ready-made meals instead of cooking already-bought food.	[22]
Bad marketing practices	Promotional offers and oversized packaging result in overbuying.	[22] [19]
Unwillingness to consume leftovers	Some people link eating leftovers with “poor people's behaviour” and end up just throwing leftovers away. Also links with Good Host or Good Provider Identity	[19]

Kasza et al (2020) observed that studies relying on self-reporting as the primary data collection method resulted in significantly less amount of food waste compared to studies using physical measurements [7]. It is theorized that this discrepancy was a result of the ‘compulsion to conform’ which led to the participants not recording all the wasted food.

Another notable factor noted in various studies is the current policies regarding ‘best before’ and ‘use by’ dates. EU regulations state that perishable foods past their ‘use by’ dates are unsafe to eat, and therefore it is forbidden to market them [32]. Legislation on ‘best before’ dates is not as strict and regulations for what to do after are generally left up to the member states, however, in some Member States the legislation is similar to that of the ‘use by’ dates and therefore they cannot be used [33].

2.2.1. Consequences of Food Waste

Food waste precipitates a multitude of consequences. Indeed it leads to environmental, social, and economic burdens [34] [35].

2.2.1.1. Indirect Consequences:

An important aspect related to the consequences of food waste is that not only does the disposal of such waste cause a negative impact, but all the previous negative effects resulting from the production, processing, transport, preparation, storage, and distribution are also compounded in the overall net negative of the waste [22]. It has therefore been argued that in future studies and statistics, this data should also be included [36].

Food production in itself has numerous environmental impacts. These include methane production from livestock farming, especially from ruminants. Methane production is estimated to account for 39.1% of the total greenhouse gas emissions [37]. Fertilizers used for the production of food for both animals and humans release nitrous oxides and ammonia which result in acidification and eutrophication of the environment [36]. All energy and subsequent greenhouse gas emissions resulting from the transportation, storage, preparation, and cooking of the wasted food are also needlessly squandered.

As a result of the indirect consequences of food waste, it could be concluded that the later in the supply chain that the food, is wasted the worse the environmental impact would be. As a result, wasted meat (beef) is the most consequential when wasted [36].

2.2.1.2. Direct Consequences:

When waste is produced it needs to be further processed through Waste Management Practices (WMP). These processes produce a significant amount of negative environmental impacts including decreased land space, release of ammonia and greenhouse gasses, and groundwater pollution [15].

According to the FAO, the amount of food waste produced equates to 1.4 billion hectares of land, 250km^3 water, and 3.3 billion tons of produced greenhouse gases [1].

Food waste production increases the potential for global warming. It is estimated that it is responsible for 15-16% of greenhouse gas production in the food chain [36] and accounts for 6.8% of total annual greenhouse gas emissions [38].

Land waste is a major factor when it comes to food waste. It is estimated that in Europe 32.2% of food waste is disposed of via landfills [39]. This great amount of waste results in a large amount of used-up land resources. Apart from the land waste, landfilling is also responsible for several negative effects on the environment such as greenhouse gas emissions, odour, and pollution of the water table [40]

Other waste management practices include incineration, composting, and anaerobic digestion. However, these also produce several negative environmental effects such as greenhouse gas production, eutrophication, and acidification [41].

Furthermore, food waste imposes significant costs on the economy worldwide. For example in Australia, food waste is estimated to annually cost upwards of 20 billion Australian Dollars [42]. This provides another layer of waste to be taken into consideration.

2.2.2. Solutions to Food Waste

Food waste is one of the most pressing issues we face today. To combat food waste the United Nations established Sustainable Development Goal 12.3. This goal aims to reduce the amount of food waste by 50% at the retail and consumer stages [43].

Furthermore, the EU Circular Economy Plan aims to prepare for reuse or recycle 60% of the municipal of all EU Member States' waste by 2030 [44]. The circular economy aims to replace the more traditional linear system for dealing with food waste (production of food waste → incineration or landfill) with a more sustainable cycle in which food waste is converted into

useful products [45]. If this is successful nothing will be wasted, and the vast nutrients found in food waste are recirculated within the food supply chain.

In order to aid with the Circular Economy Plan the EU provided a hierarchy of solutions [33].

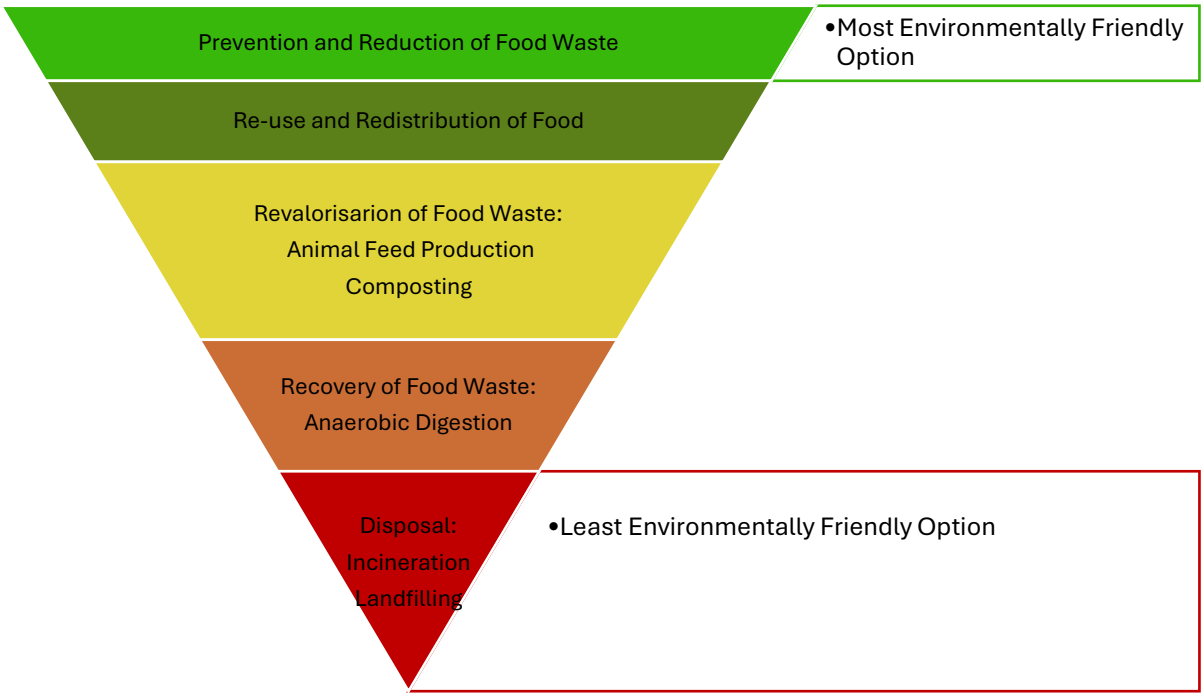


Figure 1: Hierarchy of Management of Food Waste

The Hierarchy as detailed in Figure 1 goes as follows: Prevention → Re-use and Redistribution → Recycling: Production of Animal Feed → Composting → Recovery: Anaerobic Digestion → Disposal: waste treatment via incineration → Landfill.

2.2.2.1. Prevention:

Prevention of Food waste is the best solution to food waste in that there is no waste at all. This can be achieved via changes in regulations, policies, information campaigns, educational programs, and so on.

Campaigns focusing on food waste prevention have to be developed on both national and multinational levels [7]. Furthermore both low- and high-income people need to be educated. This is necessary as food waste at the consumer level happens in both; while there is an overall higher amount of waste produced in higher-income areas, food waste in lower-income areas is particularly important due to the financial constraints they already face [19].

Additionally raising awareness is imperative not only on a consumer level, but also on a systemic level, involving producers, retailers, and policymakers. Research is needed to expose the problem areas, develop tactics, and offer good strategies to consumers [36].

A substantial implementation that could be made on a multinational level is the altering of regulations regarding 'best before' dates. As stated previously, on an EU level, regulations regarding this are left up to the Member States and this resulted in some Member States using legislation similar to that of the 'use by' dates and therefore they cannot be used [33]. This prevents not only the marketing of food which typically has only reduced in quality and not in safety [22]. One possible solution for this is the replacement of the best before' dates with Time-Temperature-Indicatory devices which indicate when food is actually unsafe [46] [47].

Improving policies on packaging can also help in the reduction of food waste. Modified Atmosphere Packaging can help in the prolonging of the shelf life of certain products [48]. Decreasing packaging on more perishable items will help the consumer get the exact amount of food they require, thus reducing food waste [11]. Reducing package size and packaging consisting of mixed items have also been recommended as a way to decrease food waste [48].

National campaigns focused on educating the consumer are also of great value [49] [50] [51] [52]. Szakos et al put particular emphasis on childhood education to cultivate innate favourable behaviour [31]. This will then result in consumers who are more environmentally aware, which has been statistically shown to decrease food waste [34] [53]. Educating the public on better storage, meal planning, and how to effectively utilize food waste in cooking will help to further reduce waste [19] [54].

Two other suggested ways to reduce food waste are smart fridges and mobile apps that list food inventory [22]. This will help to prevent over-purchasing and may even help in the reuse of leftovers.

2.2.2.2. Re-Use and Redistribution:

Donation is a very effective tool in combating food waste. Not only does it prevent food from being wasted, but it also serves as a tool to aid in increasing the food security of certain individuals [33].

A risk when it comes to donating food is the observance of the expiry dates. Ways of overcoming this can be seen in the previous subsection.

2.2.2.3. Recycling:

To properly manage food wastage at the consumption stage there needs to be active participation from the consumer, namely in food purchasing and disposal [55]. This can be achieved by implementing taxes and fees for mandatory separate collection, and/or the implementation of economic initiatives such as discounts [22] [56].

In a study performed in Italy, Borrello et al (2017) proved that consumers are willing to alter their behaviour and accept alternate food sources for animals. More than 78% of respondents showed a willingness to participate in alternate waste disposal when provided with an economic incentive (ex: a discount based on the amount of organic waste collected) [56].

In the case of recycling, food waste is seen as a resource instead of a liability [30]. It is composed of nutrients and minerals that would otherwise be wasted; therefore, this has led to increased recommendations of using food waste as a source of animal feed [57]. Revalorization of food waste into animal feed will lead to not only economic benefits but also environmental benefits [30]. Furthermore according to Secondi et al (2015) reusing leftovers is one of the best ways to reduce food waste [21].

In the case of composting research has shown that people are willing to try when given the proper initiatives, such as a home composter or monetary benefits. A good solution for people who do not have the space to compost is community composting [34].

2.2.2.4. Disposal:

Disposal of food waste is at the bottom of the hierarchy and should be prevented as much as possible, therefore more research and policies are required to reduce this.

One way to prevent the disposal of food waste is through waste separation. This could aid in the recycling of waste instead of it ending up in a landfill. Statistics for waste separation are not the best with 65% of the EU having separate waste collection but only a 40% participation rate [36].

People are more likely to separate their waste in the case of frequent and at-home waste collection [56]. Therefore policies should be for this to be achieved.

2.3. Revalorisation of food waste

As discussed previously, food waste generation and disposal are detrimental to the environment, however its formation is an inevitable eventuality in most households. One way to combat this is simply a change in perspective from the traditional linear production of food waste to a circular economy. The core tenet of circular economy is the preservation of resources through cycles of reuse which will then result in reduced carbon levels and environmental impacts [58]. In terms of food waste the circular economy tends to focus on upcycling the waste into higher value products [56].

The main ways to revalorise food waste as stated in the EU's Circular Economy Plan are composting, anaerobic digestion, and rendering into animal feed [33]. Some other applications for food waste recycling are in the biotechnology, cosmetic, and pharmaceutical fields [59].

2.3.1. Composting and Anaerobic Digestion

Composting is the process by which organic waste undergoes aerobic decomposition via a number of biological organisms to transform into a nutrient-rich dirt which can be used as an additive to soil or as a substitute for synthetic fertilizers [41]. Recently, this approach of recycling food waste has become more popular worldwide on a household level as a sustainable solution for dealing with organic waste [56]. Figure 2 below illustrates the way composting fits into the circular economy theory.

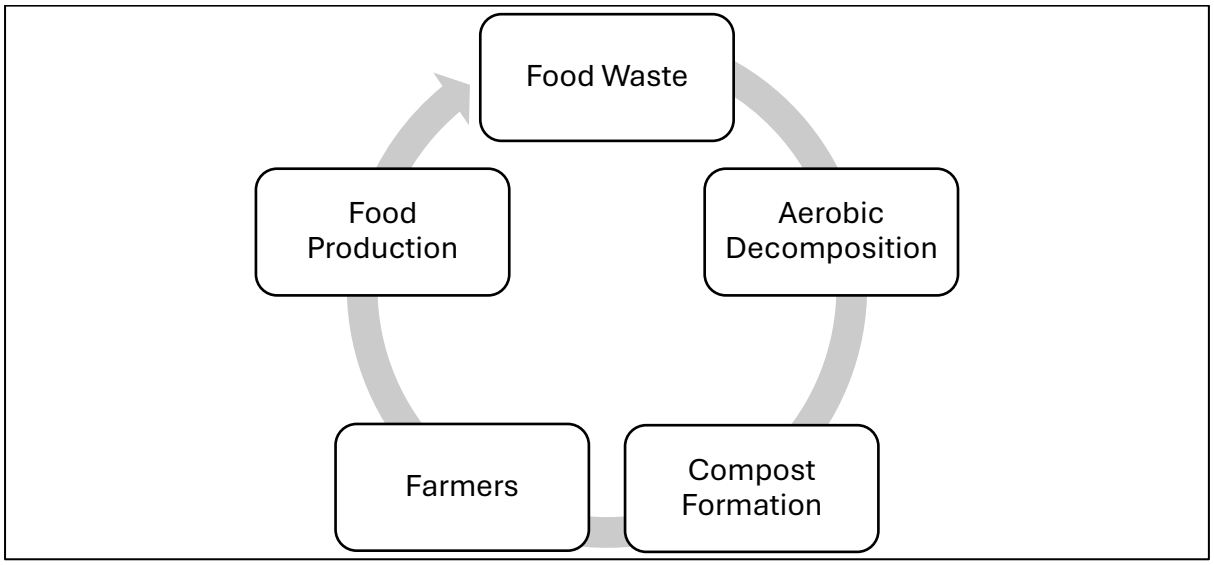


Figure 2: Circular Economy Cycle for the Revalorisation of Food Waste into Compost.

Compost can also be a byproduct of other sustainable methods of dealing with food waste. In an experiment performed by Siddiqui et al (2021), liquid fertilizer was collected as a byproduct of the conversion of food waste into animal feed [30]. Furthermore, when compost is produced on an industrial level, an incidental product that is generated is methane which can be utilized to generate electricity [60].

Kunszabó et al (2022) performed a study to research behaviours and perceptions of people regarding the composting of food waste. Even though people who were more environmentally conscious showed greater rates of composting, it became apparent that most people were open to the idea with the right incentives such as receiving a free compost bin and concessions for fees related to garbage collection [34].

Anaerobic Digestion is the process by which organic waste undergoes anaerobic decomposition to produce biogas which can then be utilized to generate electricity [60]. This method of recycling food waste has gained popularity in recent years, especially on large municipal, regional and national levels, after which the electricity generated by the biogas plants are fed back into the national grids [61]. The process offers opportunity to produce digestate fluid or cakes which are rich in nitrogen, phosphorous and potassium as a by-product to the biogas production. These materials can be used as fertilisers for crop production [41]. The cycle as per the circular economy can be visualized below in figure 3.

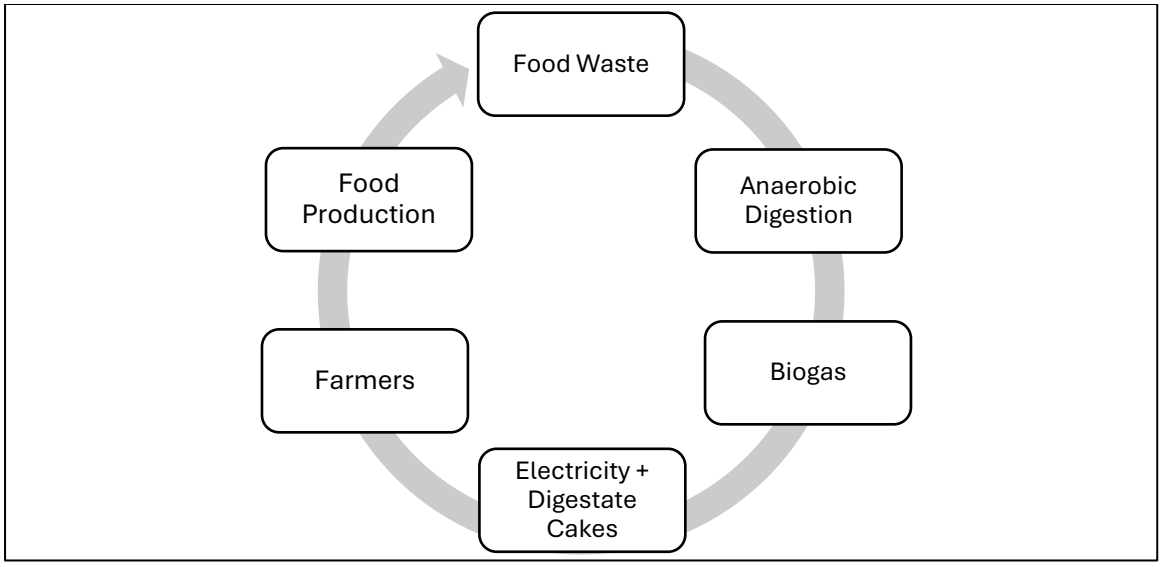


Figure 3: Circular Economy Cycle for the Revalorisation of Food Waste via Anaerobic Digestion.

Both these methods of revalorising food waste are successful examples of the circular economy as seen in figures 2 and 3 above.

However, composting is not without flaws, and hindrances, such as the lack of space or garden, the attraction of rodents and other undesirable species and odour formation amongst others that might deter participation [34]. Furthermore, both composting and anaerobic digestion have been found to be more environmentally detrimental, than the revalorisation of food waste into animal feed, due to greenhouse gas emissions, acidification, terrestrial eutrophication, among others [41] [62].

2.3.2. Food waste as animal feed

Historically, the use of food waste as a feed source for food production animals was commonly resorted to. As a matter of fact, it is theorised that it is as a consequence of food waste being generated by humans that wild boars were attracted to early human settlements, which thus lead to the domestication of swine [63]. However, due to the increase of intensive farming and the emergence of zoonotic infectious diseases, in recent times this practice has become more or less obsolete in industrial level agriculture in most developed countries [64]. For instance in Malta, individuals caught collecting organic waste, most frequently to feed it to pigs and ducks in small establishments, are heavily fined [65].

As mentioned previously, not only does the management of food waste has numerous negative effects on the environment, but the very production of food itself contributes significantly to environmental degradation through resource depletion, deforestation, greenhouse gas emissions, eutrophication, acidification, and habitat and biodiversity loss, among others [66] [67]. Indisputably this is not limited to food produced for human use but also to feed produced for animals. It is estimated that greenhouse gas emissions resulting from feed production are comparable to methods of food waste disposal such as composting and incineration [68].

A good solution to these negative effects would be to use ingredients that have less of an environmental impact, such as the revalorising of food waste to animal feed [69]. This requires a change in perspective when it comes to viewing food waste; if food waste is considered as a resource instead of a discard then it could serve as a nutritious, environmentally conscious, and more affordable alternative to currently available commercial feeds. This is especially evident as despite the estimated need to increase food production to amount for the increasing population, there is already sufficient food being produced to feed 12 billion people [4]. In line with the circular economy theory, food waste should best be recirculated within the food supply chain as animal feed [56]. This revalorisation will also reduce costs associated with growing

and producing commercial animal feeds. For instance, it is estimated that for every kilogram of pork meat produced, the component of the production costs related specifically to the feed grain cultivation is approximately €1.90, that is more than half total production costs [68].

There have been multiple studies which investigated, and in some cases proved, that food waste could result in an adequate feed for animals [57] [40]. One such study performed by Siddiqui et al (2021), concluded that Food Waste could be 'completely converted' into chicken feed and liquid fertilizer, without the production of further waste [30]. Additionally, Georganas et al (2020), concluded that a feed formulated from food waste containing animal products would have substantially higher levels of vitamins which are crucial in the diets of swine and poultry than conventional feedstuffs composed from plants [62].

Moreover, the use of "circular feed" has been adopted by countries such as the Netherlands [70]. A feed derived from surplus food from bakeries and supermarkets is fed to poultry and swine in the Kipster egg concept and Zonvarken farm respectively. With this method there is less competition between feed and food production for animals and humans respectively, and a reduced carbon footprint [70].

Revalorised food waste into animal feed has the potential to function as a standalone feed or even as simple supplementary feed. Both these methods have the potential to reduce negative effects while simultaneously sustainably preserving resources such as nitrogen and phosphorous levels. This can be achieved by various different methods such as: solar drying; spray drying; dehydration; freeze drying; microwave drying; and silage [71].

2.3.2.1. Possible challenges

Transmission of Pathogenic Microbes:

The main challenge discussed in most literatures regarding the revalorisation of food waste into animal feed, is the transfer of pathological microbes from the waste to the feed which may then lead to disease in the animals which can then be transferred to the human consumers. The main pathogens focused on in most literatures are notifiable diseases, zoonotic diseases, spore-forming bacteria, and mycotoxins [30].

Notifiable diseases such as African Swine Fever, Classical Swine Fever, Foot-and-Mouth disease, Vesicular Exanthema, and various other zoonotic or highly contagious diseases are one of the major concerns when it comes to the use of food waste as animal feed for swine.

Similarly, using food waste as a feed source for poultry can also result in the spread of certain pathogenic diseases such as avian influenza and Newcastle disease, if proper measures are not taken [62]. Due to the Foot-and-Mouth Epidemic that occurred in the UK in 2001, which was a result of a farmer illegally feeding uncooked food waste to his swine, strict regulations dealing with the recycling of food waste were implemented across the EU [72]. While some food waste is recycled, this is a very small percentage, approximating 3% of all food waste produced [41].

Bacteria such as *Salmonella*, *Listeria*, *E. coli*, *Staphylococcus*, *Clostridia*, and *Bacillus cereus* and yeasts are also of noteworthy concern. These microorganisms are highly contagious or are spore-forming which leads to high resistance. These undesirable microbes are regulated by the EC 152/2009 and if they are present beyond the set maximum permissible levels in the produced animal feed, they are not suitable for consumption as they could lead to sickness [73]. An important step to eliminate these pathogens when converting food waste into animal feed is the drying process. This reduces water content and as such makes it less susceptible to be contaminated by microorganisms, resulting in a more stable feed [60] [74]. Heat treatment is also necessary to destroy any spores.

Proper infrastructure, specialized equipment, regulations, and standard procedures must be developed in order to mitigate the risks related to the transmission of pathogenic microbes. A Hazard Analysis and Risk-Based Preventative Controls (HARPC) system needs to be developed to determine safeguards and mitigate risks [69].

In a literature review performed by Gerald C. Shurson in 2020, it was concluded that the only hazard present after revalorising food waste into animal feed were some Transmissible Spongiform Encephalopathies (TSE) prions [69]. In order to denature prions they need to heat-treat at 133^0C under 300kPa for 20 minutes [75]. It should be noted that there is no evidence present to conclude that pigs or poultry are able to transmit TSE prions, therefore feeding food waste derived feed containing animal-by-products to swine or poultry should not be an issue.

Unwanted Contaminants:

Physical hazards, such as metals, glass, bones, and others, can result in serious injury to the animals [62]. Another notable challenge is plastic, including microplastics, which can be commonly found in food waste. These plastics, if not properly disposed of, can affect intestines and stomach due to blockages and other consequences, and can lead to the formation and leaching of harmful chemicals [30]. To mitigate this challenge, suitable solutions have to be found in terms of collection, storage and pre-processing of food waste.

Undesirable substances are another challenge when it comes to revalorising waste as animal feed. Some examples of undesirable substances include nitrites, mycotoxins, pesticides, heavy metals, and dioxins. If such substances are present above the maximum permissible levels in the produced animal feed, as detailed in EC 152/2009, they could result in sickness in the animals, which leads to poor quality products for human consumption [73]. A study performed by San Martin et al (2016), investigated this issue specifically by collecting waste samples from different sectors to analyse for levels of the previously mentioned undesirable substances. The derived findings showed that almost all the levels of undesirable substances were less than the maximum permitted limits with the exception of high nitrite levels from coffee and wine waste groups [74]. Furthermore, these antinutritional factors can be redressed during the processing phase of the food waste, and methods such as soaking, heating and extrusion can be applied to inactivate or neutralize some of them [62].

Collection Method and Time:

The longer it takes for food waste to be collected, the higher the chance for the emergence of negative contaminants. Therefore increasing the rate at which food waste is collected and treated will reduce the likelihood of harm to both animals and humans. Furthermore, the only way in which food waste can be converted into animal feed is if its collection is separate from that of other waste and is frequent enough to be relatively fresh [41]. This challenge should be more manageable as by the end of 2023, all EU Member States were required to ensure that all biowaste is collected separately in accordance with the Waste Framework Directive [76].

A solution to these issues was developed in the US back in the 1950s and 60s. Food waste was collected in special trucks equipped with sterilizing equipment. While the food waste was being transported to the swine farms, it was steamed to 100ºC for a minimum of 30 minutes [68]. Another potential solution is the pay-as-you-throw method which provides a good incentive to promote proper disposal of food waste. This has been successful in multiple countries including South Korea [77]. Further pioneering ideas are required to ensure that food waste could be a safe source of feed for farm animals, but one should also draw inspiration from past innovations to enhance solutions.

Variability of Food Waste:

Food waste is not standard when it comes to its composition. It can vary depending on the source, season, and environmental conditions. These variations may result in difficulties in maintaining a consistent feed production [30]. As a result, when revalorising food waste into

animal feed, manufacturers will have to alter their formulations based on its composition [74]. Furthermore, some minerals can cause harm if they are not at their respective adequacy levels. Salt is a major consideration to be taken during feed formation. This mineral is typically found in higher levels in food waste than in the standards given for animal feeds. High salt levels can result in salt poisoning in pigs and poultry and may also negatively affect the meat quality of the final product [62]. A possible solution to this challenge is to use feed formulated from food waste as a supplement and not as a standalone feed.

Another possible solution was proposed by Dou et al (2017) to use centralized treatment plants to process food waste from several different sources into feed. This will theoretically result in a "portfolio effect" in which the variability is decreased as a result of homogenization [68]. In addition to this, routine sampling and nutritional analysis must be performed at standard time intervals to guarantee a safe and nutritious feed source.

Societal Concerns and Stigmas:

The use of revalorised food waste into animal feed would require certain changes in behaviour of the consumers especially when it comes to purchase and disposal [56]. This is especially true after the Covid-19 epidemic as there is an increased concern with using unconventional feed sources out of fear that a new epidemic will occur [69]. It is not only the consumers that should be taken into consideration but also farmers who may be hesitant to use feed produced from food waste due to the risk of transmissible disease [78].

Borrello et al (2017) performed a study with the aim to assess if consumers are willing to change their behaviour and challenge stigmas in terms of food waste. They concluded that with a sufficient reward, such as discounts, and aide, such as at home organic waste collection, most people are willing to alter their behaviour and accept more radical solutions regarding the collection and use of food waste [56].

Dou et al (2017), also addressed this issue and concluded that by utilizing innovative and effective marketing, rebranding this feed as a commodity can replace the stereotypical "garbage feeding" image into a more appealing and moreover desirable resource [68].

Regulations Regarding Animal By-Products (ABPs):

EU Regulation 1069/2009, also known as the Animal By-Products Regulations [79], focused on the safe handling, categorization, use and proper disposal of any material which contains ABPs. There are 3 categories in which ABPs are classified. Category 1 includes any material of high risk that includes anything which may be infected with Transmissible Spongiform

Encephalopathies, pet animals, specified risk materials, and any ABP which exceeds permitted levels of residues. Category 2 includes manure, products containing residues of veterinary drugs within permitted levels, animals which did not die for human consumption, foetuses and any other reproductive materials that are not intended for use. Category 3 include ABPs which are fit but not intended for human consumption, animal blood from healthy animals, and animal feed, among others [79]. Only waste from Category 3, with the exception of hides, hooves, feathers, hair, skins, adipose tissue, and catering waste, can be used as animal feed, as long as they are processed under specific requirements [80].

EU Regulation 142/2011 focuses on the rules regarding the handling, use, and disposal of ABPs that are not intended for human consumption. It includes all sectors which deal with ABPs from feed production facilities to waste processing facilities. It details the conditions required for all facilities that handle ABPs. It also provides specifications and guidelines for the use of ABPs in animal feed, however it also prohibits the practice of using processed animal proteins for the production of animal feed [81].

A couple other regulations which are germane to the revalorisation of food waste including ABPs into animal feed are Regulation 178/2002, which deals with feed safety standards and traceability, and Regulation 185/2005, which sets hygiene standards an requires the implementation of hazard analysis and critical control point (HACCP) systems [82] [83].

These Regulations provide challenges to the revalorisation of food waste into animal feed when it comes to the processing of waste containing animal proteins. These Regulations will need to be evaluated and revised in order to allow for this process whilst also maintaining the safety standards and residue limits listed in them [80].

2.3.2.2. Poultry

Poultry is the most consumed protein animal source worldwide, with 140 million tons of poultry meat being consumed in 2023 [84]. Feed costs are one of the major costs when it comes to the poultry industry and can account for upwards of 70% of all costs [64]. Therefore, it could be concluded that substituting commercial feeds with one processed from cheaper materials, such as food waste, would result in a significantly reduced production cost. This is a good manifestation of the circular economy theory as shown in figure 4 below.

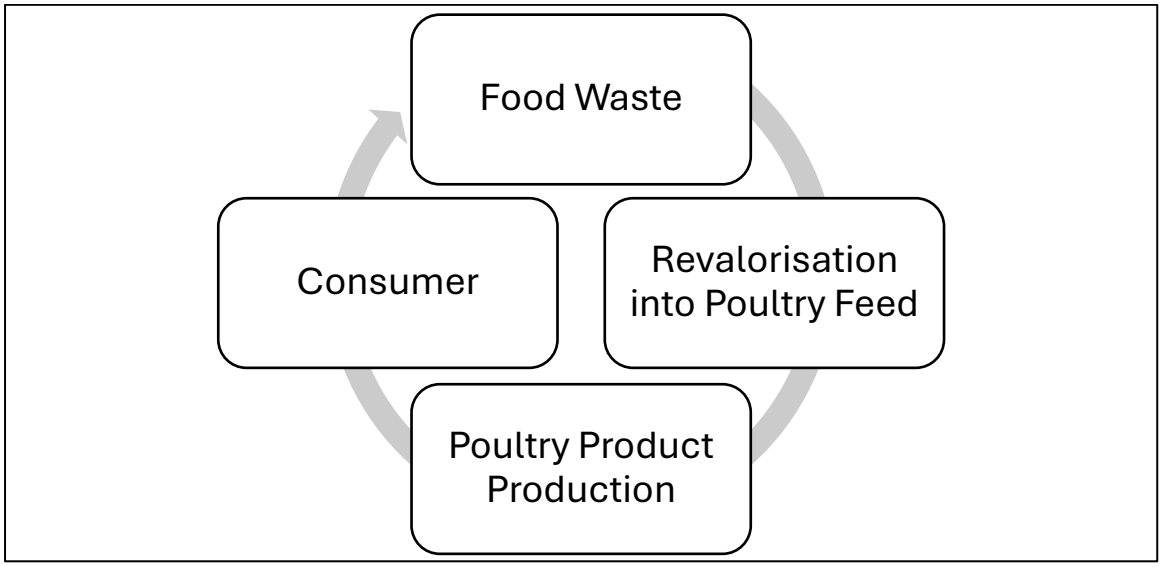


Figure 4: Circular Economy Cycle for the Revalorisation of Food Waste into Poultry Feed.

In a paper authored by Siddiqui et al (2021), the step-by-step process of converting food waste into chicken feed pellets was detailed. Furthermore they performed analysis of the macronutrient and the micronutrient contents of the feed to compare with the nutritional requirements of poultry. From this analysis it was determined that a high protein feed can be achieved, with ratios of 18.7% protein and 15.1% fat, which is similar to the values of commercial feeds. However, the percentages of the amino acids were not similar to the recommended values. [30]

Mechkirrou et al (2020) performed a similar experiment with the same goal to prove that organic waste can be successfully converted into organic chicken feed. In this case a lab prepared food (LPF) was used as the origin point which was obtained from kitchen waste such as fruits, vegetable peels and leftover food. The LPF is then sundried, sterilized, and milled to form granulated feed. Unlike the previous experiment the prepared feed was then given to the two group of 10-week-old chicks for approximately 11 weeks. Every week the daily food consumption, weight gain and total food consumption were measured and compared to official

standards. The carcass yield was also compared to official standards on slaughter. Mechkirrou et al (2020) concluded that whereas the average daily gain was lower than standards, the carcass yield was similar to official standards and as such this LPF is a substantial source of feed for poultry. [85]

Wai Chun et al (2020) conducted a research study which aimed to produce chicken feed from food waste with consistent nutrients that meet the standards set by current legislations. Food waste was taken from four different sources: residentials; hospitals; hotels and restaurants; and the wet market and then processed in their respective group's batches with a uniform method. After the food waste was successfully transformed they conducted a comprehensive analysis of the feed. The pH, glucose content, carbohydrate content, chemical oxygen demand, moisture content, crude protein content, crude fat content, crude fibre content, total ash content, total energy content, phosphorus content, and chlorine content were all measured and compared with the required standards of chicken feed. Most of the nutritional quantities were comparable with international standards, with only the phosphorous content being too low and the moisture content being slightly too high. It was argued that this could be easily rectified by supplementing additional phosphorous and allowing the feed to dry out for a longer period of time. [64] An interesting point noted is that when sterilizing the food waste, the applied temperature was 121^0C, which is as previously mentioned 12^0C less than the temperature required to denature prions. A possible improvement would be to sterilize at 133^0C to account for this possible hazard.

Truong et al (2019) further compiled multiple articles which concluded that broiler chickens fed food waste did not have significantly differing performances than broilers fed on a more typical corn and soya-based diet [60].

2.3.2.3. Swine

Pork is the second most-consumed protein source of animal origin worldwide, with 110 million tons of pork meat consumed in 2023 [84]. Similarly as in the case of poultry farming, one of the major costs of pork production is the cost of the animal feed and replacing the quantity of commercial feeds required with a cheaper option, such as revalorised food waste, will have a significant impact not only on pork costs but also on the related negative environmental effects. This is also a good example of the circular economy theory as shown in figure 5 below.

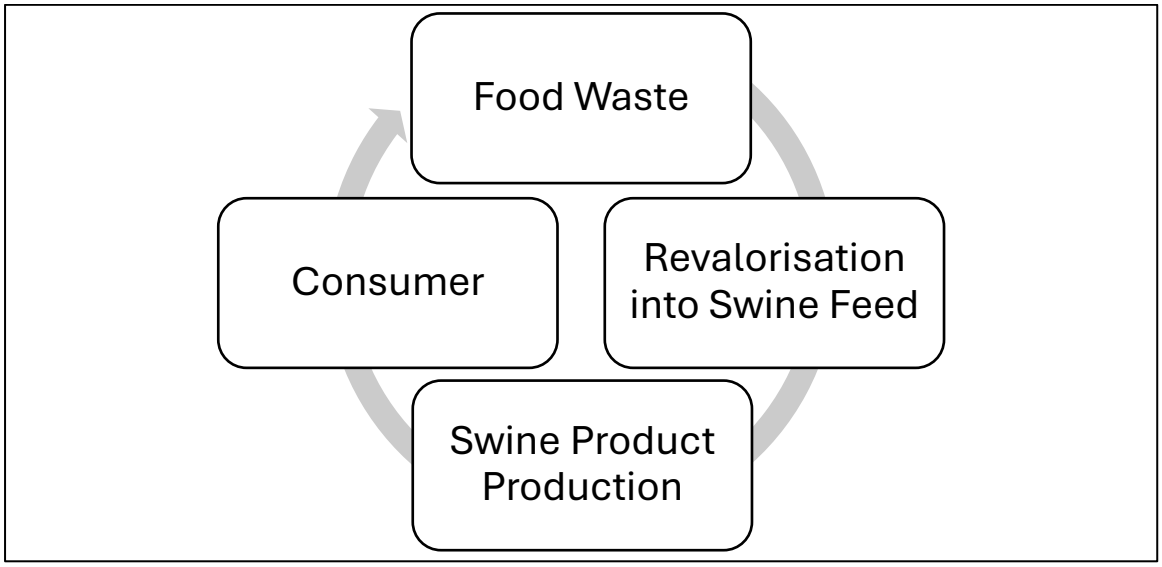


Figure 5: Circular Economy Cycle for the Revalorisation of Food Waste into Swine Feed.

In a study by Salemdeeb et al (2016), the health and environmental impacts of converting one metric ton of food waste into dry pig feed, wet pig feed, anaerobic digestion, and composting, were evaluated and compared. All stages of production were taken into consideration such as transportation of raw materials, storage, greenhouse gas formation, and more. Fourteen environmental and health impacts were taken into consideration and each of the four categories were then given a rank between one to four, with one being the best and four being the worst. Wet swine feed achieved the best average score (1.1), followed by dry pig feed (2.2), then anaerobic digestion (3.3), and composting got the worst average score (3.4). [41]

Jinno et al (2018), performed an experiment to investigate whether enzymatically digested food preparation made from food waste is an adequate source of nutrition in pigs or not. In their experiment they used two groups: a control group which was fed a standard corn and soybean feed and the experimental group which was fed a liquid diet composed of enzymatically digested food waste. The prepared feed and the end-of-line pork products were both analyzed for several factors such as dry matter, crude protein, nitrogen content, amino acid composition,

crude fiber, minerals, and fatty acids among others to be able to properly compare values to be able to conclude the effect of a feed formulated from food waste. Some slight variations were observed between the formulated and standard feeds with the only two factors being the greater amounts of fatty acids, and low zinc. While the zinc could be supplemented, the high rates of fatty acids can result in lipid peroxidation which would have negative effects on the meat quality. It also resulted that the animals fed on the formulated feed had a slower rate at which they gained weight and a lower overall weight by the time of slaughter, however this was theorized to be a result of the fact that the formulated feed had a higher water content than standard feeds. Despite this the formulated feed was concluded to have the required nutrients and the pigs showed better feed conversion with the formulated feed. [86]

In a literature review performed by zu Ermagassen et al (2016), they analyzed a number of studies regarding the effects of feeding a food waste-based animal feed to swine. They concluded that pigs fed on a feed composed of revalorized food waste had a similar meat end-product quality when compared to pigs fed conventional feeds. To this regard only two of the eighteen factors measured had a detectable decrease in quality, and even these were not highly significant. Furthermore, some of the factors reflected a positive change in quality such as an increase in marbling and an improved fat free lean percentage [87]. Furthermore, in a study performed by Sasaki et al (2007), it was determined that pork meat from swine fed on a feed formulated from food waste was of better quality than that of swine fed on a commercial diet [88].

2.3.2.4. Insects

A relatively new and innovative solution for dealing with food waste involves the use of insects. Food waste could be used as a nutrient source for insects such as maggots, mealworms, flies, and crickets [89]. These insects can then be farmed and processed into a nutrient source for farm animals. Taking into consideration insects' ability to transform discarded food into a high-quality protein source without harming the environment and also the fact that they are already a part of the natural diet of most farmed animal species such as pigs, chicken, and fish, then it could be argued that they are an ideal food source for farm animals [90]. It should also be noted that the insects which are most suited to recycle waste are also the same ones used to produce animal feed [56]. This is another good example of the circular economy theory as shown in figure 6 below.

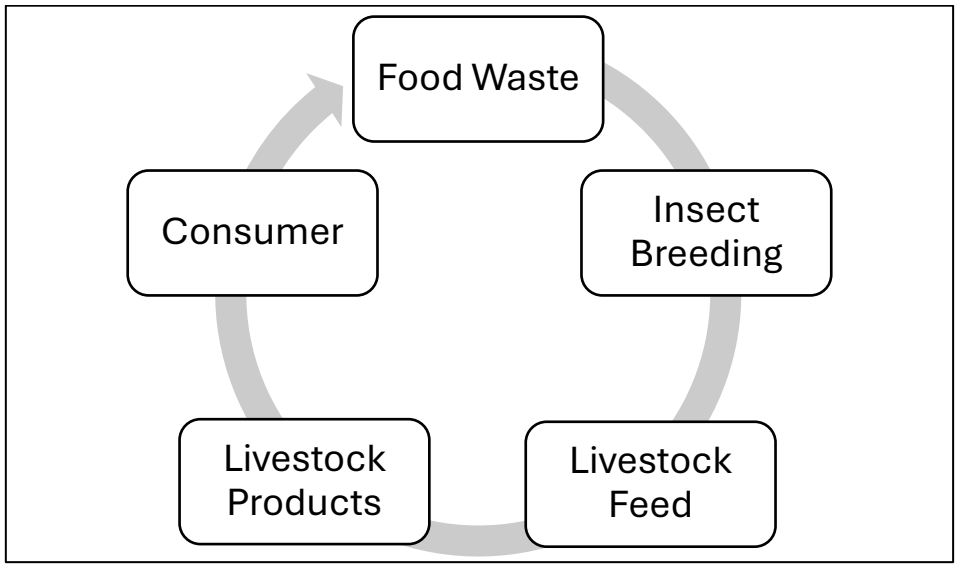


Figure 6: Circular Economy Cycle for the Revalorisation of Food Waste into Animal Feed via Insects

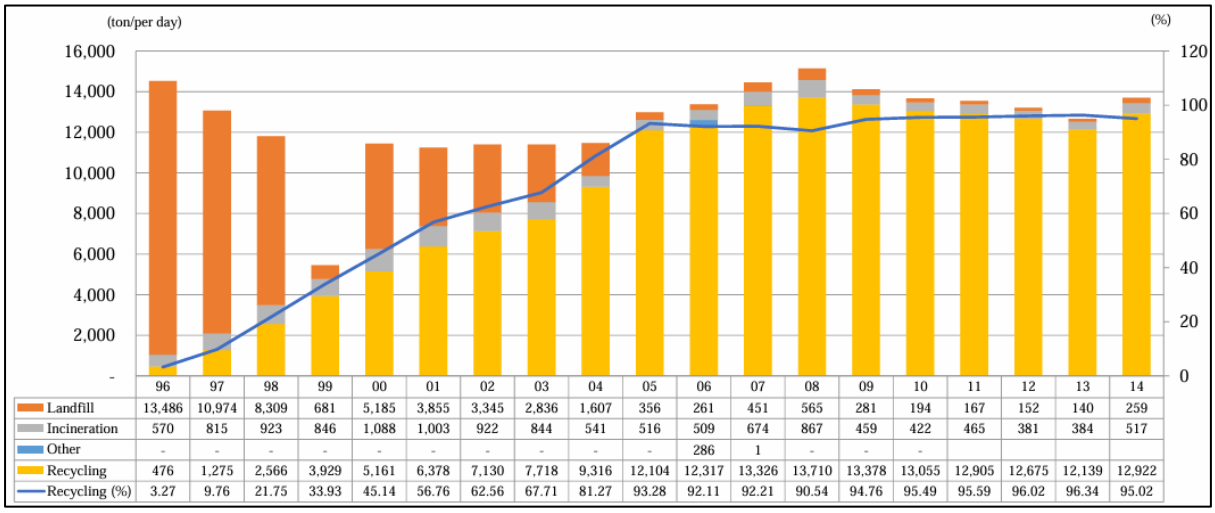
A prominent method of utilizing insects to recycle food waste to produce animal feed is through the *Hermetia illucens,* which is commonly referred to as the Black Soldier Fly [91]. This arthropod is very effective at upcycling organic waste to produce larvae which are easily harvested and nutritious comprising of approximately 44% of protein and 33% of fat [92]. Additionally, this insect is a non-pest fly, which means that it poses no risk in terms of disease spread and physical distress in the case of an incident. In an experiment performed by Diener et al (2011), their setup resulted in a reduction of food waste content by 68% whilst simultaneously producing 252g of prepupae daily [91]. This amounts to a generation of approximately 110g of protein and 83g of fat every day.

Under current EU Regulations 1069/2009 and 2017/893, it is not authorized to feed food waste containing animal by-products to insects. Furthermore, insect-based feed is not permitted in the swine and poultry industries [93]. These regulations could be revised in order to be able to make full use of this sustainable solution to both reduce food waste while simultaneously producing an environmentally friendly feed source for swine and poultry [94].

2.4. South Korea as Proof of Concept

South Korea is one of the leading countries in the use of food waste as animal feed. In 2021, 51% of food waste generated in South Korea was recycled as feed, in processes strictly regulated to ensure proper heat treatments, storage, and transportation [78]. It has also been estimated that if the EU follows similar rates of food waste recycling, it will amount to approximately 20% of all feed required for EU swine farms, which equates to 1.8 million hectares of land [87].

Directly landfilling food waste has been prohibited in South Korea since 2005 with less than 1% of all food waste produced being landfilled every year [95]. In 2013 a "Pay-as-You-Throw" policy was introduced with the aim to reduce the quantity of food waste by requiring people to pay a fine which is dependent on the quantity of food waste thrown out. This economic incentive was successful in reducing the quantity of food wasted as by 2015 there was a 30% reduction [78]. These trends of recycling food waste can be observed in Figure 7 below.



	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14
Landfill	13,486	10,974	8,309	681	5,185	3,855	3,345	2,836	1,607	356	261	451	565	281	194	167	152	140	259
Incineration	570	815	923	846	1,088	1,003	922	844	541	516	509	674	867	459	422	465	381	384	517
Other	-	-	-	-	-	-	-	-	-	-	286	1	-	-	-				
Recycling	476	1,275	2,566	3,929	5,161	6,378	7,130	7,718	9,316	12,104	12,317	13,326	13,710	13,378	13,055	12,905	12,675	12,139	12,922
Recycling (%)	3.27	9.76	21.75	33.93	45.14	56.76	62.56	67.71	81.27	93.28	92.11	92.21	90.54	94.76	95.49	95.59	96.02	96.34	95.02

Figure 7: Food Waste Recycling Trends in South Korea [78]

South Korean regulations state that food waste must undergo heat treatment at a minimum of 80^0C for 30 minutes before being used at feed. It can then be processed into wet feed with a moisture content of approximately 70-80% or dehydrated at 390 °C to produce a dry feed [87]. However, as a result of an African Swine Fever outbreak in 2019 which could have been related to animal feed production from food waste the formation of wet feed was restricted, and an increased focus was placed on dry feed formation [96].

3. Objectives

The key objective of this thesis is to analyse the generation of food waste and to evaluate the most efficient ways to utilize it, particularly with a focus on the circular economy principles. Particular focus is placed on the potential of revalorising food waste as animal feed. This will be achieved through a comprehensive review of existing literature to examine ongoing research and current practices in different countries, as well as contributing directly to an empirical study to quantify food waste generation in Hungarian households and to evaluate the extent by which it is already being used as animal feed.

4. Materials and Method

This section details the methodology used to compile data regarding food waste composition and quantities in Hungarian households, whilst factoring in socio-demographic characteristics.

Our study followed the FUSIONS methodology. The Food Use for Social Innovation by Optimising waste prevention Strategies (FUSIONS) project, which was financed through European Commission funds, was developed with the aim to tackle food waste by standardizing food waste monitoring and developing a harmonized food waste policies across EU member states [97]. The main aspects of the FUSIONS methodology regarding the measurement of food waste generated at a household level are outlined below:

- All waste generated should be measured and noted down;
- A diary should be kept by household members to record the generated food waste;
- A description of the solid and liquid organic waste should be presented in the diary;
- Regular contact between the researcher and the households in order to address any challenges, foster participation, and ensure that the diary contents are reliable;
- The sample should include one hundred households at a minimum.

In Hungary the FUSIONS methodology has been used five times: in 2016, 2019, 2021, 2022, and most recently in 2023. This has resulted in the compilation of comparable data regarding food waste amounts and formulations, which will be detailed in the results section below.

The most recent study performed in 2023 commenced with a media campaign. The media outreach took place in October 2023 and included radio interviews, television ads, and press releases. Household sampling was done on a voluntary registration basis.

There were 501 households that participated in this study, totalling 1388 individuals. The data collection took place between the 03 November until 22 December 2023. This sampling period avoided all holidays that could have introduced an unbalance to the results.

A kitchen scale and a measuring glass was provided to each household participating in the study. A manual detailing the difference between the waste types (avoidable, unavoidable, potentially unavoidable) was also provided. This was done in order to achieve an accurate and standard result across the different households. The different definitions of food waste that were provided are as follows:

- Avoidable Food Waste – Any food or drink thrown out which was edible at any point prior to disposal. Examples include bread, meat, and apples.

- Unavoidable Food Waste – Any organic waste that was never edible under normal circumstances. Examples include bones, eggshells, vegetable peels, and tea bags.
- Potentially Unavoidable Food Waste – Any food or drink thrown out that certain individuals consume while others do not, or that could be eaten when prepared in special ways. Examples include bread crust, apple peels, fat, and other foods that are often avoided by people who suffer from various health disadvantages (e.g. digesting problems, chewing complications due to denture problems or cardiovascular disease).

Prior to the start of the experiment a special emphasis was placed on the fact that all data collection was anonymous in order to reduce the likelihood of potentially inaccurate data. All the socio-demographic characteristics of the participants were collected via a questionnaire that asked for data regarding the geographical location, household size, income level, age, sex, and qualification. Each household had to weigh and record all food waste generated in grams prior to disposal for seven days. They were also instructed to record the generated waste as accurately as possible, for example “bread crust” as opposed to “bread”. Participants had the option of recording the data gathered on an online platform or by keeping a hard copy. All data collected was then consolidated into a unified waste log.

Throughout the data collection period, continuous support was provided to the participants via email and telephone communication. Furthermore, the supporting unit was also responsible for the procurement of the scales and measuring glasses, compiling all the data from the diaries, receiving and vetting all the volunteer applications, keeping contact with the participants, and maintaining motivation.

Following the collection period, a post-hoc validation of the data collected by the participants was performed. The data was next analysed for each household and extrapolated into statistics regarding per capita food waste generation and annual food waste production. The gathered data was then compared to that collected in the previous studies and to produce national Hungarian statistics for the EU Commission. The dataset was officially sent to Eurostat and presented at various EU forums.

During my thesis work, I was able to work together with the research team at the Department of Applied Food Science, therefore my questions were included in the questionnaire, and I could follow and support the process of data collection and data analysis. Based on the primary research data, I was able to conduct my calculations and elaborate my arguments included in the Discussion section.

5. Results

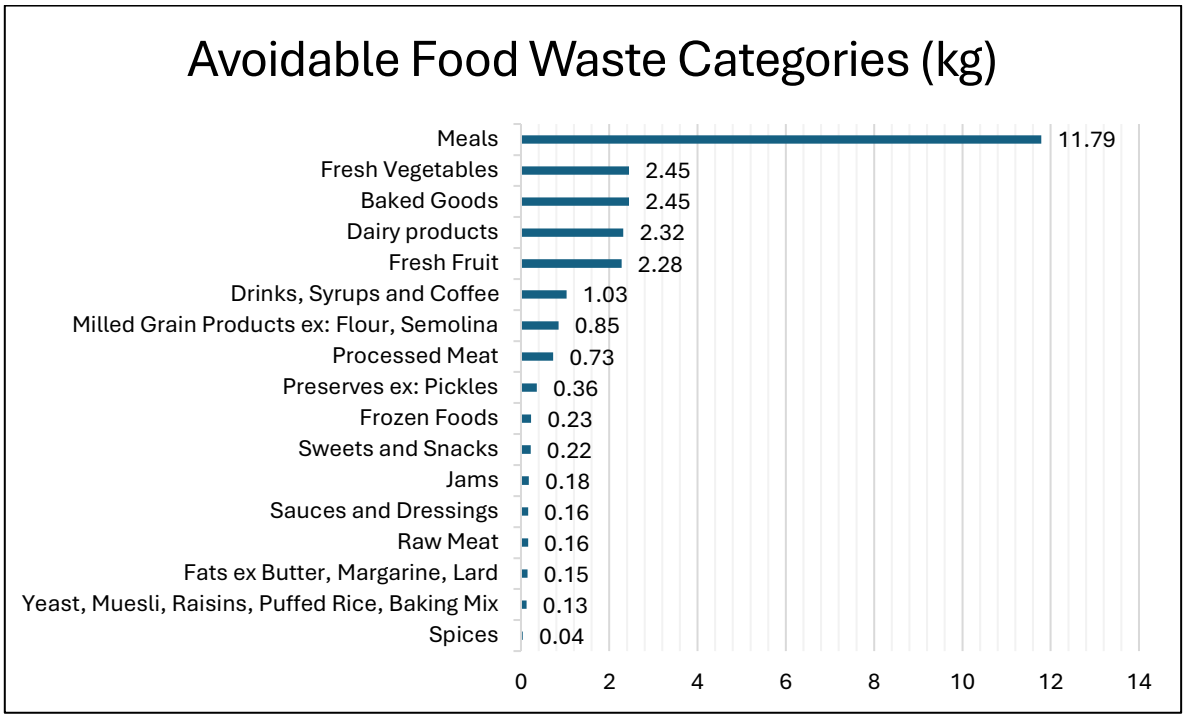
501 households with 1388 participants participated in the study, and these generated a total 235.6 kgs of food waste during the measurement exercise. From this data, the annual per capita food waste was extrapolated to be 61.96kg. The distribution of the generated waste according to category is detailed in Table 2 below.

Table 2: Extrapolated amount of generated food waste per person every year (kg).

	Liquid	*Solid*	*Total*
Avoidable	6.6	19.2	25.8
Non-avoidable	0.9	30.9	31.81
Potentially avoidable	0.63	3.72	4.35
Total	8.14	53.82	61.96

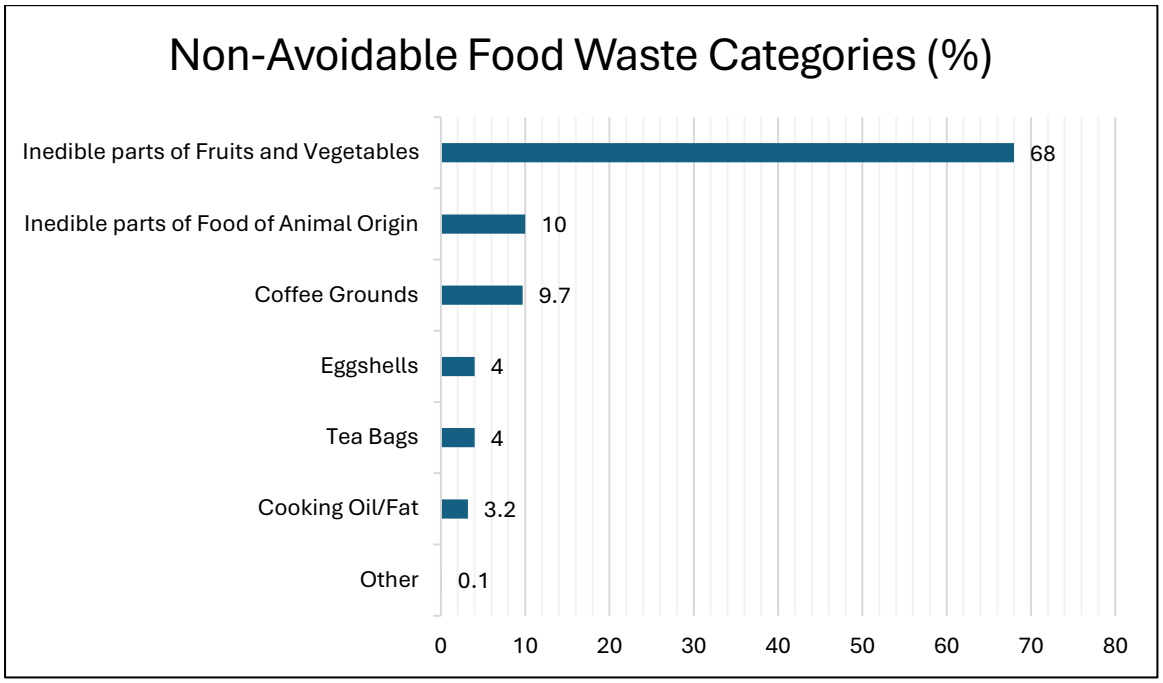
The percentage of Avoidable Food Waste amounted to 41.7% of the total food waste. The most common food types in this category were meals, baked goods, fresh vegetables, dairy products, and fresh fruit. In total eighteen different food categories were outlined based on the gathered data which are outlined below in Table 3 below.

Table 3: Proportions of Avoidable Food Waste Categories.



The percentage of Non-Avoidable Food Waste amounted to 51.3% of the total food waste. The most common food types in this category were inedible parts of fruit and vegetables such as seeds and peels, inedible parts of food of animal origin such as bones, and coffee grounds. In total seven different food categories were outlined based on the gathered data which are outlined below in Table 4 below.

Table 4: Proportions of Non-Avoidable Food Waste Categories.



The percentage of Potentially Avoidable Food Waste amounted to 7% of the total food waste. The most common food types in this category were chicken skin, bread crust, and edible fruit and vegetable peels.

Liquid Food Waste generation accounted for significantly less than solid food waste, comprising only 13.1%. The most common liquid food types were soft drinks, syrups, coffee, and cooking oil.

Data was also collected regarding the methods of food waste disposal - these can be visualized in Figure 8 below. The most common incidence was for food waste to be disposed of - at 47.61%, with composting being the second most common option at 25.77%, and feeding to animals being the third at 15.4%. The participants were further asked as to which animals they fed their leftovers to, the results of which can be seen in Figure 9 below. The most common animals mentioned at more than 50% were dogs, followed by poultry at 19%, and cats at 16.8%.

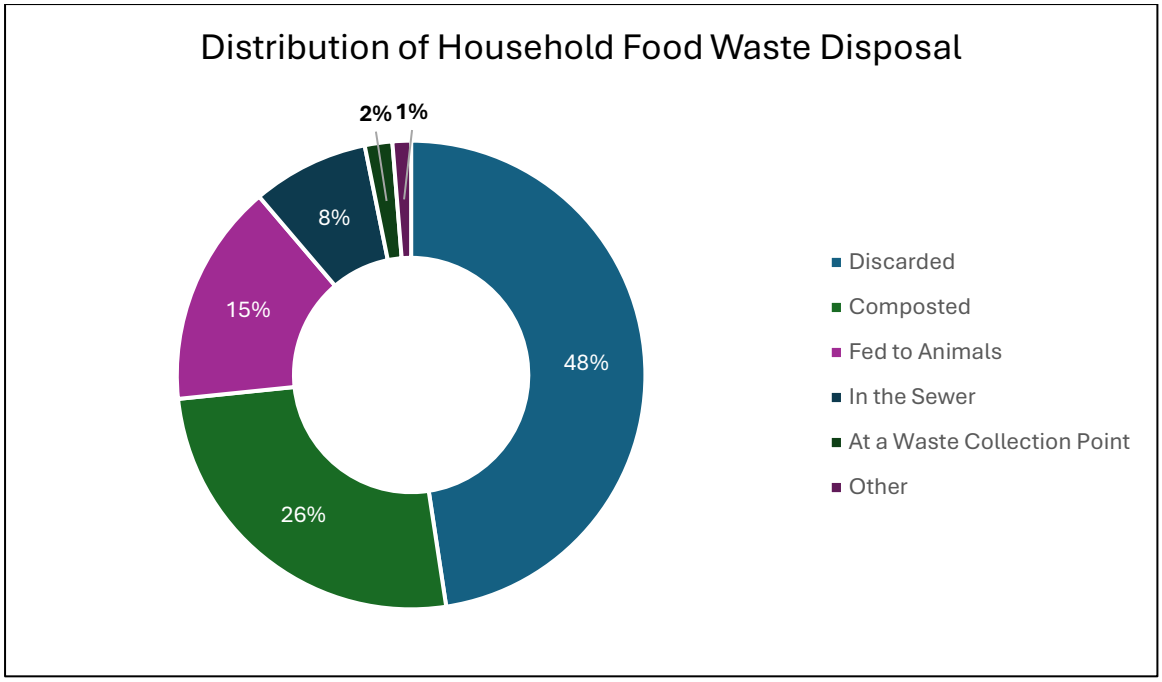


Figure 8: Distribution of Different Methods of Household Food Waste Disposal.

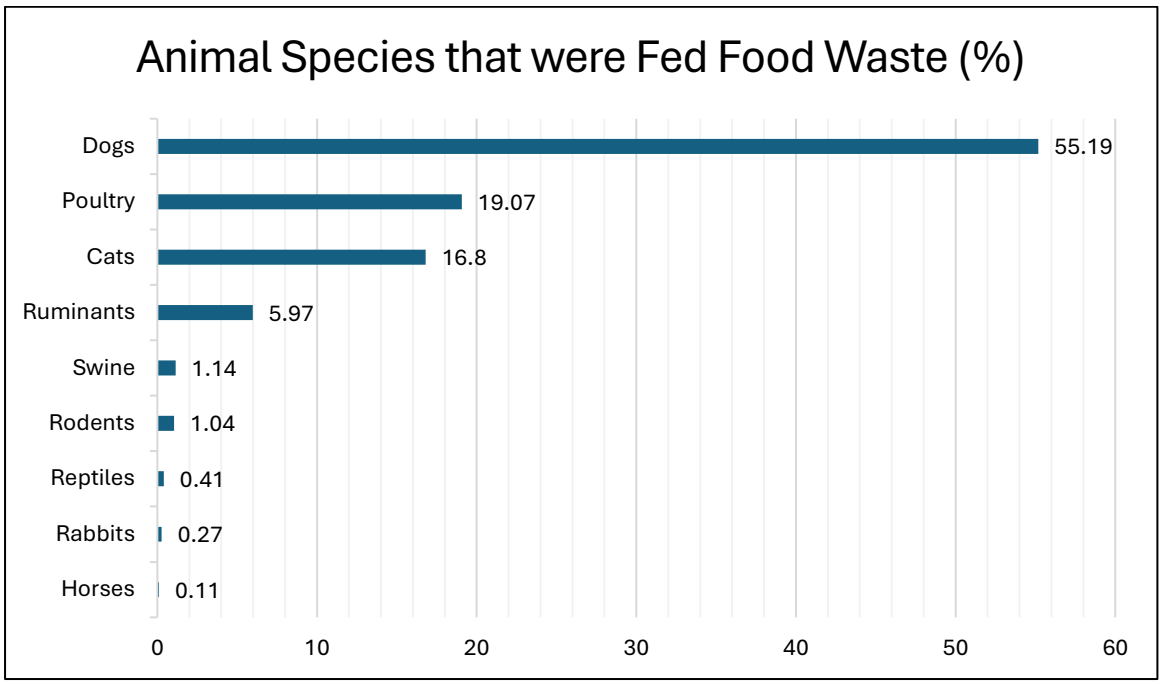


Figure 9: Percentage of Animal Species fed Food Waste.

Finally, the factors that resulted in the production of food waste were compiled into 18 different categories, as demonstrated in Figure 10 below. The most common reason given was that the food had been forgotten - at almost 1/4th of all responses, followed by cooking too much, and over-buying.

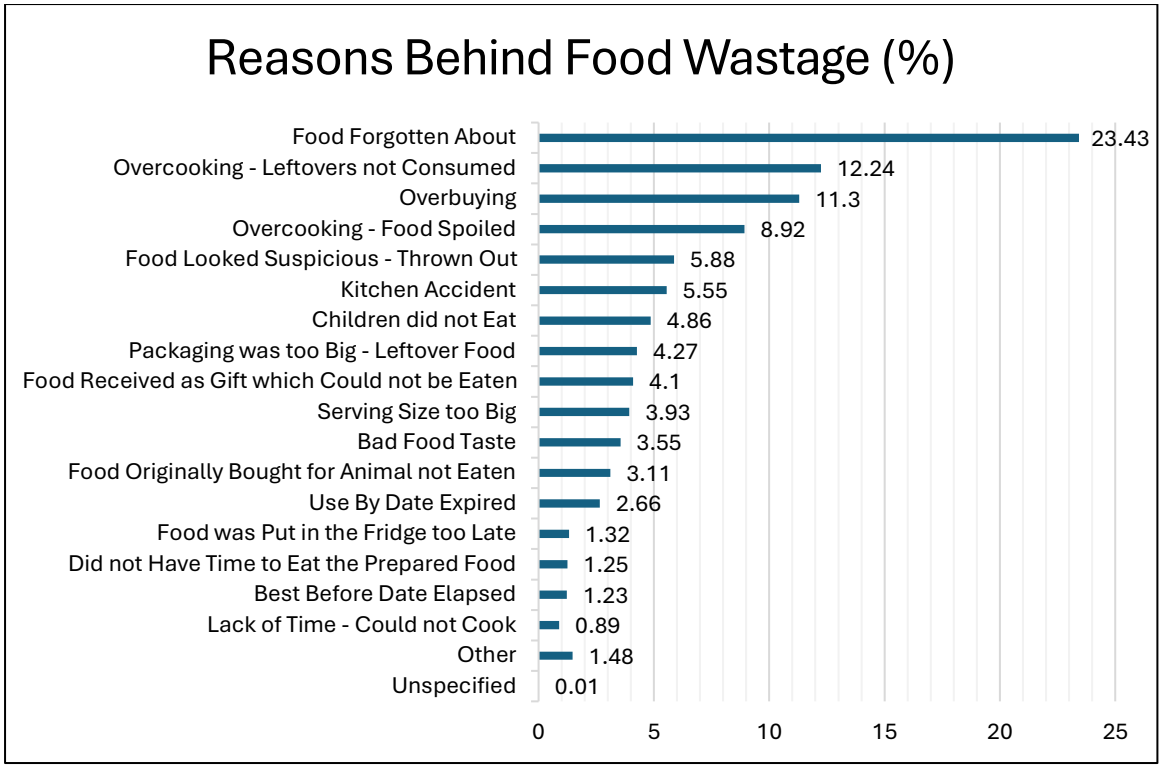


Figure 10: Reasons leading to Food Waste.

6. Discussion

A third of all of the food produced in the world ends up discarded, totalling up to a staggering 1.3 billion tonnes of food wasted annually [1]. The most common waste management practices utilized to deal with generated food waste are landfilling and incineration [39]. These practices have very negative environmental impacts, such as greenhouse gas production, nitrate leaching, and acidification among others [15]. Therefore more sustainable approaches to dealing with food waste are required. This is where the importance of the Circular Economy Theory is evident.

The Circular Economy Theory's central tenet is that the traditional linear systems currently in use should be replaced by sustainable cycles in which food waste is transformed into useful products [45]. Examples of this premise can be visualized in Figures 2-6. However, in order to be able to maximize the potential of this theory research is required to quantify and analyse the waste that is being produced.

The research detailed in this thesis aims to do just that by determining the composition and proportions of food waste generated in Hungarian households. Results of such waste (Table 3) characterization reveal that the highest proportion of edible food waste at 46.2% were meals, which included both homemade meals and ready-to-eat ones. This was followed by fresh vegetables and fruit which, combined, account for 18.5% of all food waste. Bakery products (9.6%) and dairy products (9.1%) also made up a significant proportion of food waste. These perishable food groups made up 83.4% of the total amount of avoidable food waste.

This study had also been conducted back in 2016, 2019, 2021, and 2022. This allows for comparison of the trends that have manifested themselves in this time span. Throughout these years meals have consistently been the predominant source of generated food waste. Whilst there is an 11% decrease in the number of meals wasted since the very first study, the previously observed trend of reduction in waste quantity was halted by this studies outcome, with an increase of 17% of wasted meals when compared to the previous studies value. Fruits and vegetables show a similar trend of overall decrease from original study (-15.7%) there was an increase from the previous study (+4.4%). On the other hand, bakery products have decreased at a constant rate with a 62.3% decrease from the original study and a 9.9% decrease from the previous study. The quantities of collected edible food waste over all the previous studies can be observed in the table below.

Table 5: Quantity of Edible Food Wasted of top 3 Contributors

Year	*2016*	*2019*	*2021*	*2022*	*2023*	
Fruits and Vegetables	5.61	5.94	4.46	4.43	4.73	Kg/capita/year
Meals	13.28	13.7	10.74	10.06	11.79	Kg/capita/year
Bakery Products	6.50	5.31	3.43	2.72	2.45	Kg/capita/year

The data collected can also be compared to other studies produced in different countries. A notable comparison to be made is that the factors resulting in food waste are similar across countries. Households with children, bad shopping habits, bad food preparation and storage, time constraints, too big packages, and an unwillingness to consume leftovers are all reasons given by other studies as contributing factors for the generation of food waste. Another key aspect to food waste generation is the best before and use by-dates. These have been cited as the reason for food waste in a number of studies apart from this one. The international trends indicate the main points that need to be targeted in order to reduce food waste, not only in Hungary but also on a global level.

An interesting result identified in this study is that 15.4% of all generated food waste was fed to pets, with dogs, poultry, and cats being the main recipients. This would indicate that approximately 90,000 metric tonnes of food waste is fed to pets in Hungary. Considering this significant amount of food waste that is being fed to pets, there is a pressing necessity for further research in this field. Upcycling food waste as pet feed would fit into the circular economy theory, however research is required to assess if this would be a safe and feasible method of feeding pets. The benefits of this strategy can be better appreciated on considering that with these values of food waste an average household can feed 3.25 hens in an optimistic scenario, and when strong limitations are factored in, 1.17 hens. The hens would then cover a significant part of the egg consumption for the household resulting in a sustainable use for food waste, with on average 250 eggs produced per hen annually.

These figures were arrived at in the following manner:

- 1 person produces 62kg of food waste annually.
- 15% of these are fed to animals, including poultry. Therefore approximately 90,000 metric tonnes of food waste is fed to animals in Hungary.

Optimistic scenario with no limitations:

- Average household = 2.3 people [98]. Therefore household food waste (2.3*62kg) = 142.6kg annually, or 0.39kg per day.
- 1 laying hen requires approximately 0.12kg of feed daily [99]. Hence the average household can feed (0.39/0.12) = 3.25 hens.

Pessimistic scenario with strong limitations:

- Adverse food components (such as bones, coffee ground, cooking oil, tea filters, fluids totalling 18kg per person) are removed from 62kg of originally generated food waste, and the remaining 44kg was halved (due to possible spoilage that prevents usage as feed) = 22kg of food waste suitable as animal feed annually per person.
- Average household = 2.3 people. Therefore, household food waste available for feeding (2.3*22kg) = 50.6kg annually, or 0.14kg per day in an average household.
- 1 laying hen requires approximately 0.15kg of feed daily. Hence the average household can feed (0.14/0.12) = 1.17 hens.

It should be noted that this theoretical calculation does not take nutrient content and need into account and is solely based on the mass of food waste and the required feed.

Unlike in the revalorisation of food waste into pet feed, reutilizing organic waste into animal feed for farm animals such as swine and poultry has been researched and in some countries even implemented on national levels. Countries such as South Korea have successfully recycled their food waste into animal feed for decades. However, as indicated by past events, this method of dealing with food waste is not without risk, especially in the case of diseases such as African Swine Fever and Foot and Mouth Disease. Therefore, we need to learn from the countries that already have methods and processes in place and develop appropriate infrastructure specialized equipment, regulations, and standard procedures on an EU level. It is also required for certain legislation to be updated in order to utilize innovative solutions for dealing with food waste. This is especially important when it comes to utilizing insect-based systems for organic waste decomposition.

In the research there were some limitations which could have influenced to final results. The primary limitation faced during the study relates to the participants. Even though each household had a relatively short sampling period of seven days constant engagement and participation was not necessarily achieved. Furthermore, due to the lack of a financial

incentive, a higher proportion of more eco-conscious participants was more likely to participate in the study, hence possibly influencing the end results. Another possible limitation could be that throughout the survey period, the participants could have been more conscious of the amount of waste they produce and consequently resulting in lower amounts of waste generated during the study. Moreover, participants may have possibly recorded less discarded food quantities than were actually generated, which we were not able to supervise or control. That said, the duration of the measurement period and the fact that households were researched as opposed to individuals should have mitigated some of the factors that could instigate skewing of results. It must be noted that also the season of the study could possibly deliver a variance into the measured data, due to the fact that people tend to buy (or produce) and consume more fruits in summer than they do in wintertime.

7. Conclusion

In a world facing severe rates of food insecurity, food waste is an important aspect that needs to be properly and more widely researched and utilised. In accordance with the hierarchy of solutions provided by the United Nations, revalorising food waste is more sustainable than composting and anaerobic digestion. It also constitutes a more environmentally friendly option as both composting and anaerobic digestion result in higher rates of negative environmental effects such as greenhouse gas emission, nitrate leeching, and acidification [41] [62]. It will also help in reducing the amount of food waste in line with the United Nations' Sustainable Development Goal 12.3. Furthermore, not only does revalorising food waste into animal feed diminish the negative effects resulting from food waste disposal but it also lessens the environmental impact of animal feed production itself.

Studies have shown that with proper incentives, people are willing to alter their behaviour when it comes to waste collection, and to partake in innovative solutions that deal with waste. Examples should also be taken from countries where the proportion of landfilled waste is less than 1% such as in South Korea, both in terms of waste collection schemes and waste treatment options [95].

In conclusion, a significant amount of food waste could be avoided. Whilst employing the data achieved from this research, public campaigns and schemes can be developed to efficiently reduce the amount of waste produced. Education regarding food waste is also necessary, and especially targeting children at a young age. Methods of utilizing food waste also requires further research. Food waste will never be completely eliminated; however targeted campaigns and effective management practices can lead to better habits and solutions for food waste production.

8. Summary

Food waste is an increasingly significant concern of international concern. Approximately 1.3 billion tonnes of food is wasted on an annual basis worldwide. A significant portion of the generated food waste is avoidable, meaning that it is composed of edible food items such as meals, baked goods, fresh produce, and animal products. Some common grounds for throwing out food include bad shopping habits, bad food preparation and storage, time constraints, overly big packaging, and an unwillingness to consume leftovers. These are not only observed in Hungary but are also prevalent in several other countries worldwide.

Food waste generation gives rise to numerous notable consequences. In Europe a significant proportion of food waste is landfilled. This is ecologically harmful, resulting in several environmentally degrading effects such as greenhouse gas emissions, acidification, deforestation, groundwater contamination, nitrate leaching and others. To counteract this, the Circular Economy Plan was conceived. In this plan a hierarchy of solutions was presented: Prevention → Re-use and Redistribution → Recycling: Production of Animal Feed → Composting → Recovery: Anaerobic Digestion → Disposal: Incineration → Landfill. The circular economy cycles of composting, anaerobic digestion and production of animal feed were investigated further.

Particular focus was placed on the revalorisation of food waste into animal feed, with special emphasis being given to generation of animal feed for poultry, swine and via insects. A number of articles were analysed to assess the viability of this possible solution. Overall, positive results were obtained which indicated that food waste could successfully and safely be revalorised into animal feed. This was further proven by the inclusion of data from South Korea, where this practice has been in place for several decades.

This study also presents results emanating from a research study, which followed the FUSIONS methodology, to measure food waste generated in Hungary at a household level. I participated in this study alongside the research team, by fielding questions and subsequently analysing data. Sampling was performed on a voluntary basis and in total 501 households (1388 participants) participated in the research. The data collection period occurred in late 2023, during which the households had to weigh and record all food waste generated in grams prior to disposal for seven days. Eventually, a post-hoc validation and subsequent analysis of the data were performed. Methods of food waste disposal and factors leading to it were also investigated.

From this research, the annual per capita food waste resulted in being 61.96kg. The percentage of Avoidable Food Waste amounted to 41.7%, the Non-Avoidable Food Waste to 51.3%, and the Potentially Avoidable Food Waste to 7%. The methods of food waste disposal and reasons behind the food waste were also investigated.

Interestingly, this study resulted in that 15.4% of all generated food waste was fed to animals (pet and food animals around the household). This provides a new and noteworthy point of investigation. According to my ensuing theoretical calculation, an average Hungarian household could feed their food waste to one or two hens (potentially up to 3.25, according to different scenarios), which would cover a significant part of their egg consumption.

This thesis identifies new scopes for research that can ultimately lead to more sustainable solutions to food waste.

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