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# Toward sustainable bioeconomy: Assessment and feasibility of biofuel production from food waste in the Netherlands

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**Toward sustainable bioeconomy: Assessment and feasibility of biofuel production from food waste in the Netherlands**

Master Thesis

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## ABSTRACT

The Netherlands on one hand has a high amount of food waste per capita and on the other hand the country is low on land and forestry resources. Thus considering high dependency of Netherlands on fossil fuels, especially natural gas, conversion of food waste to biofuel provides an opportunity to tackle food waste issue as well as achieving bioeconomy targets. In this manner, part of the biomass needed to achieve the mentioned target for bioenergy production could be supplied by biofuels produced from food waste. However production of biofuel from food waste is complex due to technological difficulties and costs. The aim of this research is to study to what extent is it feasible and practical to convert food waste to biofuel according to Dutch targets and ambitions for sustainable bioeconomy. So that, the existing research estimates the capacity of biofuel production from unavoidable food waste in the Netherlands regarding to existing data and information on food waste and technology. Further it discusses the policies to facilitate production and consumption of food waste based biofuels. According to the results a potential of maximum 5.74 PJ bioenergy production using hydrochar is possible from unavoidable food waste of Dutch household. While the costs for developing the technology to achieve this capacity is a critical point, reviewing policies revealed that having specific policies such as bio waste separation in household contributes to moderate the costs of biofuel production from food waste.

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# CHAPTER I

# INTRODUCTION

## *1.1 Research background*

Due to global population growth a 70% increase in global food supply is anticipated, accordingly the world food supply should provide food for over 9 million people by 2050 (Horizon 2020, 2018). On the other hand as estimated, nearly 50% of the globally supplied food and 30% of food in developed countries is wasted. Disposal of food waste by methods such as landfilling and even incineration leaves obvious negative environmental impacts and. Hereby, conversion of food waste to different types of biomass and biofuel contributes to solve the problem of food waste disposal at some point by reusing and entering it into a cycle of circular economy (Lundi & Peters, 2005; Dung et al., 2014).

Alongside what have been mentioned, bioenergy is a type of eco-friendly energy that contributes achieving a sustainable development goals and also CO2 emission reduction globally. To this extent European Union target for greenhouse gas reduction aims at aims at 20% of carbon emission reduction by the year 2020 compared to 1990. Therefore, within this framework bioenergy plays a big role. Particularly biofuels are supposed to replace the current generation fuels to contribute reaching the emission reduction goals (Capros et. al., 2008).

However bioeconomy could be considered as a potential momentum for pushing sustainable development forward by providing clean and renewable energy as well as contributing for carbon emission reduction, meanwhile the bioeconomy system must be sustainable itself. Discussing European Union policy on bioenergy, it is necessary for biofuels and bioliquids to meet the minimum amount of greenhouse gas savings (Scarlat et al., 2015a). Thereupon, stepping into sustainable bioeconomy and looking for more eco-efficient and circularity in raw material is unavoidable. The term sustainable bioeconomy firstly points on utilization of sustainable raw material input and also applying the circular economy theory in bioeconomy.

In order to achieve a sustainable bioeconomy, shifting from fossil raw material to renewable resources for bioenergy production is crucially important (Sillanpää &

Nacibi, 2017). Further another major challenge in bioeconomy expansion is the high amount of land use for biomass production (Hertel et al. 2013). According to the problem mentioned first about food waste, this resource could be considered as a renewable raw material alternative in sustainable bioeconomy and also deal with the unavoidable food waste recycling issue itself.

### *1.2 Research gap*

Regarding the Dutch energy portfolio, the country is highly dependent on fossil fuel, particularly natural gas, for supplying heat, electricity and power. Due to 2012 statistics, more than 90% of the consumed came from fossil fuels (Deloitte, 2015). Meanwhile, the country aims at increasing the share of renewable resources up to 14% until the year 2020. In this manner, the projections for future bioenergy in the Netherlands represents a remarkable increase in biomass, biogas and liquid biofuels production (Panoutsou & Uslu, 2011). However bioenergy could benefit Netherlands a lot by reducing dependency on natural gas and providing clean sustainable energy, there are still challenges in promotion of this type of energy.

Woody biomass shapes a relatively huge part of utilized biomass in the Netherlands including both waste wood products, wood pellets and wood chips. Concerning the numbers, 90% of the wood pellets and 10% of the wood chips that used as biomass are imported. Discussing the carbohydrates production as bioenergy production raw material the country was able to self-supply half of its carbohydrate consumption. Nevertheless the raw material for carbohydrate production consists food and feed such as wheat, maize and potato that brings up the debate about food and energy tradeoff as well as land use for producing these material (Goh & Junginger, 2015).

According to a 2013 assessment, the Netherlands has been estimated to have the highest amount of food waste per capita among all European Union countries by 541 kg per year (Kretschmer et. al., 2013). Therefore as there is no national plan for food waste reduction in the Netherlands yet (Aramyan & Velva, 2016). Furthermore, currently Netherlands highly relies on incineration of food waste. However incineration of bioresources could generally fit in the platform of bioeconomy but according to several research works is not environmentally friendly and also the energy value of valorized food waste is normally higher than when incinerating. Hence it is not a solution to achieve sustainable bioeconomy (Okoro et. al., 2017).

With respect to what have been discussed about developing a sustainable bioeconomy model and food waste situation in the Netherlands, using food waste as feedstock to produce biofuels leads toward tackling the food waste problem as well as achieving a sustainable bioeconomy model concerning biofuel production (Katsarova, 2014). The aspects of food waste valorization and its contribution to sustainable bioeconomy will be elaborated in Chapter 2.

Accordingly, as conversion of food waste to biofuel is a relatively a new concept in practice with high complexity regarding technology and policy tools. The first and foremost topic which should be determined concerning this context, is to what extent is it food waste a feasible bioresource to be used as feedstock in biofuel production. On this basis, the next section discusses the research objective.

### *1.3 Research objective and questions*

This research deals with valorization of food supply chain waste into biofuel. As explained in the previous section the Netherlands has high amount of food waste which causes various problems. Also due to its chemical elements of food waste has high potential to be converted into different forms of biofuel and consequently bioenergy. This would also facilitates the road towards a bio-based economy model. Hence, The objective of the research is to firstly study the feasibility of converting food waste to biofuel in the Netherlands concerning the Dutch sustainable bioeconomy targets, and further providing analysis as well as a suggestions for policy-making and strategic planning of food waste biofuel production in the Netherlands based on reviewing the existing condition as well as the results derived from analyzing the technology and capacity of biofuel production from food waste.

In order to fulfil the main research objective it is necessary to formulate research question with consideration of different factors that deal with costs and benefits of food waste conversion to biofuel. Thereupon, the research questions of this research are formulated as follows.

- ***The main Research question:***

*To what extent is it feasible to convert food waste to biofuel regarding the Dutch bioeconomy targets; which strategies and policies are needed to facilitate conversion of food waste for biofuel production in the Netherlands?*

- ***Sub research questions:***

  ***Sub-question 1****:* What is the state of the art of production and consumption of biofuels produced from food waste in the context of Dutch bioeconomy plans and targets?

  ***Sub-question 2:*** What strategies and supporting policies could facilitate the production and consumption of biofuels based on food waste based conversion in the Netherlands?

*1-4 Research approach and methods*

This thesis could be classified as an intervention-oriented research (Verschuren et. al., 2010). The approach of this research is to use desk research and existing archive of statistics and reports in the context to analyze the situation of food waste valorization to biofuel and its contribution to Dutch sustainable bioeconomy.

For this reason this research follows the following modules in its research framework as represented in Figure 1:

a. The first step to review the theoretical background in bioeconomy as well as Dutch sustainable bioeconomy targets.

b. This step includes two major sub-modules:
   Firstly, the current situation of the food waste valorization to biofuel is studied and the total amount of unavoidable food waste in the Netherlands is estimated using the existing data in reports. Estimating the total amount of unavoidable food waste is important because the biofuel produced from food waste should not compete human and livestock food.

Secondly, the value chain for production of food waste based biofuel is studied and further by using the amount of household unavoidable food waste in the Netherland, the potential volume and value for biofuel and bioenergy production is estimated and compared to the bioeconomy targets of the Netherlands reviewed in step (a). This leads toward answering the first research question.

c. This section uses the review on different existing policies on food waste and biofuels together with the analysis and discussions for food waste situation in the Netherlands and biofuel production from it to discuss how policies could facilitate production of biofuel from food waste in the Netherlands. This section answers the second sub-question.

d. Answering the first and second sub-questions in step (b) and (c) leads to answering the main research question of the research. Hence on this basis, step (d) concludes the discussions in this research.

Further, discussing the limitations of this research it should be mentioned that due to lack of data for estimation of food waste at industrial level, this research only relied on estimation of biofuel production from unavoidable Dutch household food waste as well as food waste from catering services.

*1-5 Research Outline*

The present chapter of this thesis provides introduction and an overview to the research. The second chapter of the research aims at reviewing the theoretical background in the topic of bioeconomy and discusses its terms in the Netherlands. Chapter 3 is dedicated to analyze different aspects and Dutch food waste and estimating the total amount of unavoidable food waste in the Netherlands. Following to the third chapter, Chapter 4 discusses steps and technologies required for food waste conversion to biofuel, consequently it estimates the total amount of biofuel production capacity from Dutch unavoidable food waste. Chapter 5 reviews the existing policies in European Union and Netherlands on food waste and biofuels and fuurther discusses how policies could facilitate conversion of food waste to biofuel in the Netherlands. Chapter 6, the final chapter is a conclusion.

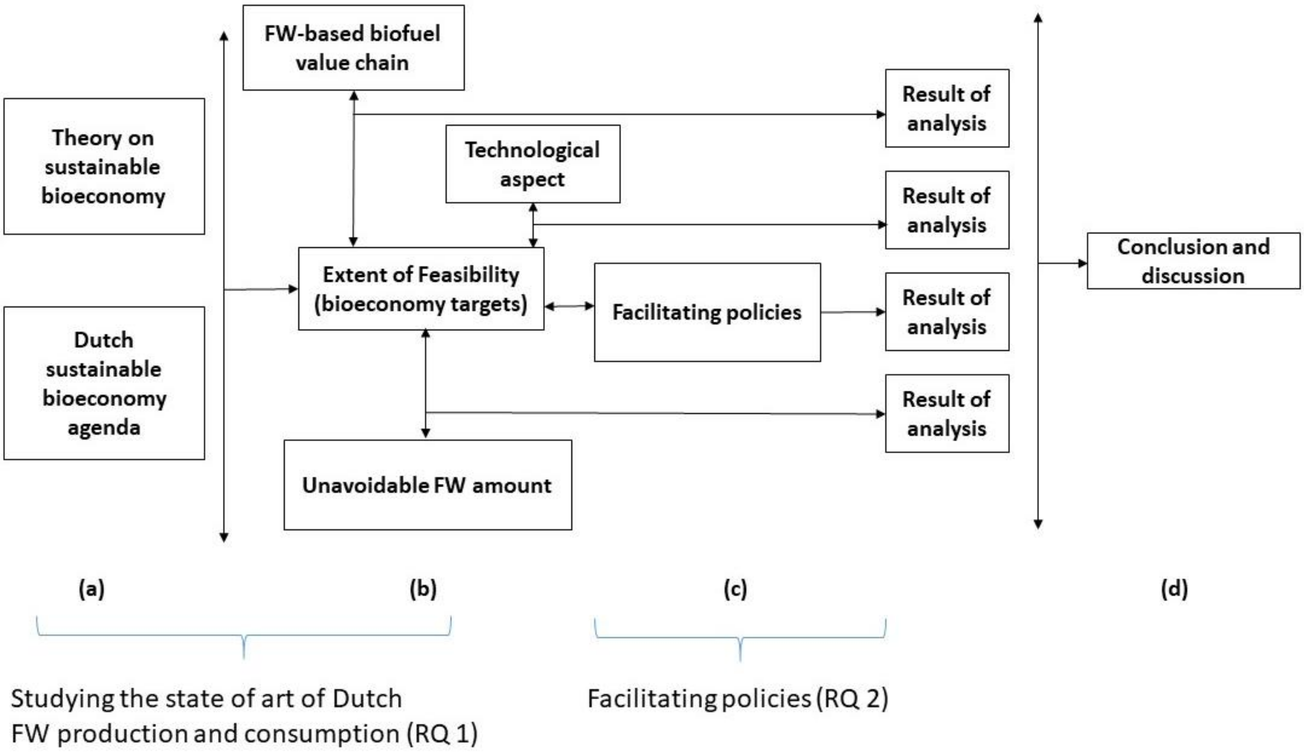



Figure 1- The research framework (FW: Food Waste)

# CHAPTER II

# THEORETICAL BACKGROUND AND DUTCH AGENDA

This chapter starts with conceptualizing the topic of this research in the scope of sustainable bioeconomy literature and theories -in the sense of where this research and food waste conversion to biofuel topic is positioned in the literature. Further it aims at studying whether and how the topic of this research (production of biofuel based on food waste as feedstock) contributes to the sustainable bioeconomy agenda in the Netherlands. To do so, the ambitions related to Dutch sustainable bioeconomy agenda is reviewed. These ambitions create a basis for analyzing the extent of food waste based biofuel production contribution to boost bioeconomy in the Netherlands in next chapters.

## *2.1 Sustainable bioeconomy economy and biomass production*

This sub-section firstly reviews the theorical background and approaches in previous research works in the field of bioeconomy to grasp an understanding of sustainable bioeconomy theoretical background and further discusses the significance of food waste as a bioresource to produce biofuels. Moreover studying theoretical background of sustainable bioeconomy clarifies the aspects in sustainable bioeconomy must be taken into account when studying food waste conversion of food waste to biofuel.

Bioeconomy is a general term for an economic model where the basic material and energy are supplied by means of renewable resources (McCormick & Kautto, 2013). Having an in depth insight into the topics that is covered by the scope of bioeconomy, there is the concept of Biobased Economy (BBE) and subsequently bioenergy. BBE is described as economic activity based on bioresources which excludes human food and feed for production of chemicals and bioenergy as shown in figure 2 (van Dam et. al., 2014; Goh & Junginger, 2015).

The ultimate aim of BBE is contributing to transition from carbon economy (that uses fossil resources) toward employment of efficient and renewable bioresources that do not harm the environment and the society.

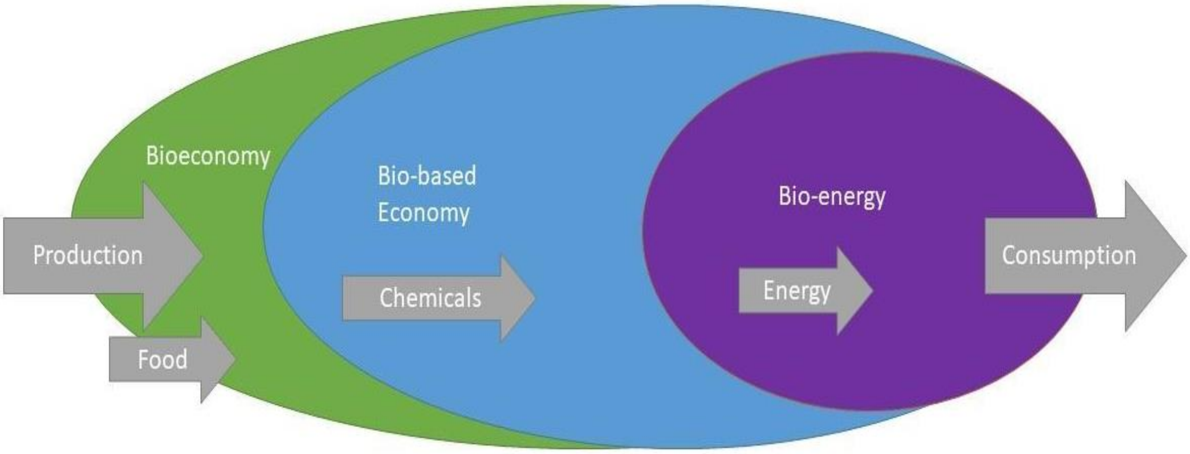



Figure 2- Scope and boundaries of bioeconomy topic (van Dam et. al., 2014)

The scope of BBE concept is vast and includes all advancements in life-sciences and biotechnology sector to biomass and bioenergy production (Bennich & Belyazid, 2017).

Discussing different theoretical approaches in BBE, there are three major approaches to bioeconomy by researchers found in the literature. On this basis, these visions could be categorized as follows:

- Bio-technology, where most of the concentration is on application and commercialization of new technologies in bioeconomy;
- Bio-resource vision, that emphasizes on raw material and the ways to process and upgrade it; and
- Bio-ecology, the vision highlights environmental and other sustainability aspects of bioeconomy (Bugge et al., 2016).

However each of the three aspects that mentioned above are each a specialized focal point in the literature of bioeconomy but there is a synergetic interrelationship among these aspects and in a macroview could not be seen separately. On this basis, the main concentration of this research is on bioresources in the sense of studying how food as a potential bioresource could facilitate advancements in the road toward a sustainable bioeconomy. Whereas the ultimate aim of using bioresources is sustainability, when having a discussion about using bioresrouces instead of fossil resrouces to step toward a bioeconomy system, considering the sustainability aspect of the bioresources is necessary. Further achieving the targets of a sustainable bioeconomy model without having the technology is impossible.

With respect to the literature of the reasearch work dealing with policy aspects of bioeconomy topic, there is an argument about the pitfall of overlooking the sustainability aspect of bioeconomy because of presuming achieving a sustainable bioeconomy model subsequently and naturally results in sustainability. Whilst there is a scientific dispute about the possible negative impacts of bioeconomy to ecology and biodiversity causing from the pitfalls of the current bioeconomy model (Pfau et al., 2014).

To this extent and in theory, this research also focuses on sustainability and technological features of bioresources. Knowing the fact that having a bioeconomy does not necessarily lead toward a sustainable future clarifies the importance of sustainable bioeconomy to make it more viable with ecology. To achieve this sustainable bioeconomy model, having sustainable bioresources is a prerequisite. The following lines describes the importance of having sustainable bioeconomy according to the European policies and the role of technology and sustainable bioresources more.

Regarding the European Union targets and ambitions, following up a sustainable bioeconomy model is important to reach the 2050 goal for low carbon economy. The European Union strategy for achieving a sustainable bioeconomy model is entitled as Innovating for sustainable growth: A bioeconomy for Europe. Within this strategy, resource efficiency has been introduced as an important pillar. The major referred actions in order to reach resource efficiency contains transition from fossil to bioresources by means of producing renewable bioresources and their conversion into bioenergy, food, feed and other by-products (Staffas et. al., 2013).

Development of a European bioeconomy action plan is supposed to also contribute for tackling societal challenges by ensuring food security, managing natural resources sustainability, reducing dependency on non-renewable resources, mitigating and adapting to climate change as well as creating jobs and maintaining European competitiveness (European Commission, 2017). According to the mentioned activity blocks for achieving a bioeconomy model in Europe and by considering energy as one of the unavoidable resources in production of commodities, it is necessary to develop innovative ideas for sustainable bioenergy production in bioeconomy system. So that, having sustainable biomass/biofuel that does not compete with human food and livestock feed is necessary due to the importance of food security in European bioeconomy action plan as mentioned above.

The importance of having sustainable biomass is also addressed in the theoritical literature, for instance Scarlat et al. (2015b) in their work illustrated the importance of biomass sustainability and biomass availability in a sustainable bioeconomy model. In order to achieve this, the authors emphasized on development of biotechnology for achieving new ideas in bio-based material production from agro-food residues and waste.

With what have been discussed regarding the theoretical background and European policies, it is concluded that using food waste as a bioresource is contributing for production of sustainable biomass to reach sustainable bioeconomy targets. However sustainability is not already a guaranteed aspect of converting food waste to biofuel and there must be criteria and assessment on what type of food waste is used to produce biofuel. Further, technology has been identified as the tool for achieving sustainable bioeconomy.

Herby, this research combines the sustainability and technological approaches to bioeconomy to study food waste valorization to biofuel feasibility. This extensive perspective contributes achieving more reliable results in the research. The sustainability aspect of food waste as a bioresource for production of biofuel is elaborated in chapter 3. This mostly deals with what kind of food waste is suitable for conversion to biofuel regarding theories with the essence of sustainability. Further technological aspect of biofuel production from food waste is reviewed by chapter 4.

Knowing the general theoretical and practical background of sustainable bioeconomy and its links to food waste conversion to biofuel, the next section of this chapter reviews to what extent using food waste for production of biofuel fits in ambition and targets of bioeconomy and sustainability in the Netherlands.

*2.2 Bioeconomy and biomass situation and ambition in the Netherlands*

Netherlands has officially implemented the bioeconomy strategy since 2007 with the main objective of sustainable biomass valorization, production of bio based material and biofuels from residues. Use of sustainable biomass is an important pillar of sustainable bioeconomy ambition in the Netherlands. In this manner the ambition for 2030 aims at achieving employment of bio-based material for 60% of transport fuel, 17% of space heating and 25% of electricity demand satisfaction. Thereupon, the first pathway for transition from fossil to bio-based resources is sustainability of biomass with an emphasis on using raw material which are originated in the Netherlands rather than imports (Goh & Juninger, 2015).

Discussing biomass imports to the Netherlands, as an example, a large number feedstock for production of woody biomass is imported from other countries to the Netherlands. Accordingly, the total amount of dry woody biomass in the Netherlands in 2012 is 3.3 Mton of which nearly 0.92 Mton (≃30%) is imported (Goh & Junginger). However due to importance of biomass and biofuels, the country is investing in production of new sustainable biofuels from waste material. Until the year 2013 nearly €120 million has been invested on several programs and research on biomass production and valorization into biofuels (Langeveld et. al., 2016). The amount of investment reflects the determination for developing biofuel based on new sources in the Netherlands owing to its importance.

The development of new generation biofuels ought to satisfy the future demand of Dutch bioenergy market and targets for biofuel consumption. The high amount of food waste in the Netherlands shows a potential for production of biofuel based on domestic bioresources and not imports.

According to Soethoudt and Timmermans (2013) in 2009 nearly 21.3% of average of the estimated unavoidable food waste in the Netherlands has been valorized to animal feed, 6.9% used in fermentation process, 22.5% has been composted, 45.6% incinerated and approximately 3% has been landfilled. As these data represent, incineration is a common method for dealing with organic waste in the Netherlands, which might help for expanding the scale of bioeconomy in the Netherlands but could be considered as a sustainable solution as it interrupts the cycle of circular economy and causes environmental pollution while conversion of food waste to biofuel does not lead to such problems (Anderson, 2007). Therefore conversion of food waste to biofuel could be considered as a sustainable solution according to what have been discussed in Section 2.1.

In order to analyze to what extent is it feasible to convert food waste to biofuel according to Dutch bioeconomy plans, it is required to know what are the ambitions of sustainable bioeconomy. At the beginning of this section the general ambition of the Netherlands for producing energy using bioresources by 2030 has been mentioned. Achieving those goals for energy production using bio-based material in the Netherlands is broken down in targets with smaller scales.

As an example, Due to high economic and environmental costs and in order to step toward bioeconomy, Dutch government are planning on closure of all coal-fired plants by 2030. The offered alternative to compensate for energy that is supplied by coal-firing plants, is employing a package of different renewable energy to achieve an accumulated production of 25 PJ in which the share of the produced energy by means of biomass is expected to be around 7.5 PJ (Warringa et. al., 2016). In an other example and with respect to transportation fuels, The Netherlands is aiming to achieve a mix of 10% biofuels mix in transportaion fuels by 2020, look at Section 5.3.2 (Lieberz, 2017).

The aforementioned policies and plans provide an opportunity for boosting sustainable bioeconomy. However the remaining question is what are the potentials of producing biofuel from food waste in the Netherlands to contribute achieving the tragets in these plans. For instance to what extent could food waste based biofuel contribute achieving production of 7.5 PJ bioenergy in the scenario of coal-firing plants closure and supplying the needs for biomass in the Netherlands.

The next chapters aim at providing an answer to this question by studying food waste amount in the Netherlands and the technologies to convert it to biofuel.

## CHAPTER III

## FOOD WASTE: THEORIES AND CURRENT SITUATION IN NETHERLANDS

The previous chapter addressed the importance of sustainability factor in bioeconomy as well as production and consumption of bioresources. Bringing this concept in the context of food waste and biofuels, it means that food waste as a bioresource must meet the sustainability criteria in the process of conversion into biofuel to contribute for stepping toward sustainable bioeconomy. Moreover after discussing the value chain of biofuel production from food, this chapter provides information and data concerning food waste state of art and quantities in the Netherlands which is used in chapter 4 to estimate the potentials of biofuel production from food waste in the Netherlands. The results and findings from this chapter contributes to answer sub-question 1 in chapter 4.

### *3.1 Food supply chain waste*

#### *3.1.1 Concept and definition*

According to the literature, there are different definitions for food supply chain waste, while the most common and general definition describes it as the discarded edible material intended for human or animal consumption. There is also another definition that considered the gap between the consumed food per capita and needed energy value per capita. These definitions do not consider the inedible residues in food supply chain, however from valorization to biofuel point of view, the non-edible organic residues within food supply chain that potentially could be utilized for biofuel and subsequently bioenergy production is considered as food supply chain waste (Parfitt et al., 2010; Pfaltzgraff et al., 2013).

Table 1 represents a general overview of food supply chain waste for different stages. According to parfit et al. (2010) the term “food waste” and ‘spoilage” is generally referred to the food loss in post-harvest stage which includes food processing and production. Hence, at the middle stages the production management, supply chain system and machinery equipment play a big role in reducing food waste as well as dividing residues for further use. In industrialized countries such as the Netherlands, the term “food supply chain” is referred to the post-harvest activities. Therefore, managing food waste in these countries mostly deals with production processes, equipment quality and supply chain management such as the cold chains.

The mentioned steps starts from pre-harvesting to post-harvesting and transportation for storage before processing in food companies. The residues in this step are so called agricultural waste or residues. Further, the next phase of food supply chain starts with primary processing in food companies and in its last node, includes post-consumer use and the product’s end of life.

The residues often contains organic residues (fruit and vegetable), catering waste (e.g. cooking oil), animal by-products (slaughter waste) and wastes in packaging and domestic use (Lin et al., 2013).

The scope of this research for studying food supply chain waste includes food processing to end of life (steps 3 to 11 in Table 1) and studying agri-waste is not included here. It should also be mentioned that the industrial waste in food supply chain also includes some amount of waste water that potentially could be converted to bioenergy. Studying that is out of the scope of this research.

### *3.1.2 Food waste valorization and sustainability*

Knowing the definition of food supply chain waste, the next step is to define what type of food waste is considered as inedible (unavoidable) and could be used as feedstock for production of biofuel. This is an important notion to meet the sustainability criteria of bioresources for biofuel production. This section provides a review on that.

In the theory, Moerman ladder provides a vision and hierarchy for the priorities of food waste usage and valorization. According to Moerman ladder adapted for the Netherlands (Table 2) to specify priorities to deal with food waste , the first priority for dealing with this issue in food supply chain is to prevent the waste as much as possible throughout the supply chain stages (Eriksson et. al., 2015).

Table 1- Major steps of food supply chain and residues/waste (Source: Parfit et. al., 2010)

| **Food supply chain step** | **Examples of food waste/loss** |
|---|---|
| 1) Harvesting | - edible crops left in field, ploughed into soil, eaten by birds, rodents, timing of harvest not optimal: loss in food quality<br>- crop damaged during harvesting/poor harvesting technique out-grades at farm to improve quality of produce |
| 2) Threshing | loss through poor technique |
| 3) Drying, transportation & distribution | poor transport infrastructure, loss owing to spoiling/ bruising |
| 4) Storage | pests, disease, spillage, contamination, natural drying out of food |
| 5) Processing (Primary processing, cleaning, classification, drying, packaging etc.) | - process losses<br>- contamination in process causing loss of quality |
| 6) Secondary processing (e.g. Mixing, cooking, frying etc.) | - Process losses<br>- contamination in process causing loss of quality |
| 7) Product evaluation (e.g. Quality control) | product discarded/out-grades in supply chain |
| 8) Packaging (Weighing, labeling, packaging) | - inappropriate packaging damages produce grain spillage from sacks<br>- attack by rodents |
| 9) Marketing (Publicity, selling, distribution) | - damage during transport: spoilage<br>- poor handling in wet market |
| 10) Post-consumer | - plate scrapings<br>- poor storage/stock management in homes: discarded before serving<br>- food discarded in packaging: confusion over ‘best before’ and ‘use by’ dates |
| 11) End of life (disposal of food waste/loss at different stages) | food waste discarded may be separately treated, fed to livestock/poultry, mixed with other wastes and landfilled |

Table 2- Moerman ladder for hierarchy to deal with food waste in the Netherlands (Source: Eriksson et. al., 2015)

| Highest priority | **Waste hierarchy** | **Moerman ladder in the Netherlands** |
|---|---|---|
| | Prevention | Prevention |
| | Reuse & preparation | Use for human food |
| | Recycling | - Conversion to human feed<br>- Use as animal feed<br>- Raw material for industry |
| | Recovery | - Processing to make fertilizer for co-fermentation<br>- Processing to maker fertilizer through composting<br>- Use for Sustainable energy *(Biofuel)* |
| Lowest priority | Disposal | Burning as waste dumping |

In this context, Hoogwijk et al. (2003) in their work presented a simplified model for biomass production flow based on the resources (land and crops) use, see Figure 1 of Annex 1. Specifically this model dichotomized the type of waste/residues from agricultural activities in primary and secondary residues. Primary resources are the ones which could be reused and recycled for products could be used by human and livestock or being employed by industry as raw material. Secondary residues are waste and losses from processing of primary residues that cannot be useful for producing food, feed and industrial raw material, so that they would be valorized to biomass. Therefore, the approach of this research is using secondary residues of food production/processing for conversion into biofuel.

Utilization of food waste/residues offers a closed-loops for agro-food supply chain alongside with less land-use for the purpose of energy corp production (Hoogwijk et al., 2003). Discussing circularity in food supply chain, Figure 2 of Annex 1 presents a general scheme of applying circularity approach to food supply chain developed. Correspondingly, valorization of food waste into valuable materials such as human food, animal feed and industrial war material has higher priority than conversion into biofuels (Rood et. al., 2017).

With respect to Moerman ladder (Table 2), Hoogwijk et. al. (2003), and Rood et. al., (2017) a simplified flowchart for assessment of using food supply chain waste has been developed in this research as presented in Figure 3. This model provides a procedure to decide what type of food waste could potentially be used as feedstock for biofuel production to meet sustainability criteria and not to interrupt circular economy cycle for food supply chain. Basically, the waste, residues and losses in the flow of food supply chain that cannot be used for reusing and recycling are categorized as secondary waste/residues and regarding to Moerman ladder could be used for biofuel production.

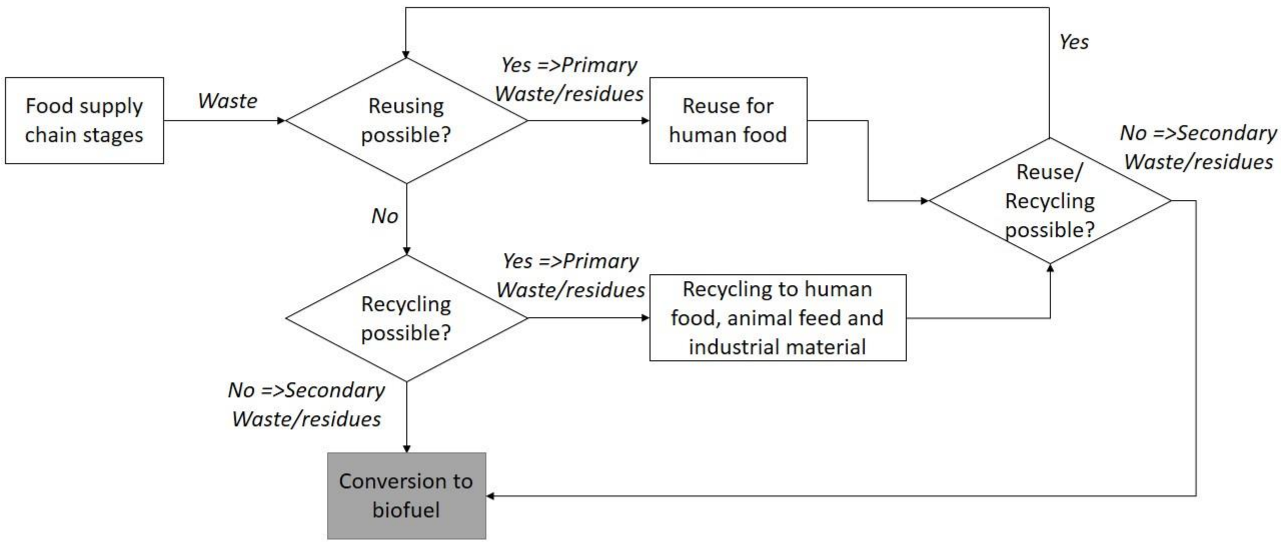



Figure 3- A model to assess food supply chain waste value for valorization based on Moerman ladder

The presented model in Figure 3 conceptualizes sustainability factor for biofuel production from food waste. The concept of primary and secondary residues covers the 3P (Plant, People and Profit) involved in sustainability notion by saving land and producing valuable commodities for society from waste based on circular economy model and social demands in Moerman ladder.

Next section discusses the current plans and activities to deal with food waste in the Netherlands. This will exemplify the practical situation of the discussed theory in this section.

*3.1.3 Food waste valorization potentials and plans in the Netherlands*

After knowing priorities for food waste treatment this section aims to review what happens to food waste in the Netherlands in practice and regarding the existing plans for dealing with food waste. The plans that has been carried out in the Netherlands for food waste valorization could be divided in two section of actions taken in industrial and household sectors.

Discussing the case of industries, according to Dutch Central Bureau for Statistics (CBS StatLine, 2018) there is a total number of 6,460 active industrial units in Dutch food industry excluding breweries. The bakeries and patisseries shape nearly half of the active companies in this sector with production of more than 1,31 million tons of bread, pastry and cake due to 2017 data (Statista Market Forecast, 2018). So that here this sector of food waste will be studied as a sample for industrial food waste treatment in the Netherlands.

Bakery waste has high potential for valorization to different type of chemicals as it is considered a rich resource for carbohydrates which could be converted to bio-ethanol. Schrauwen (2013) in her research studied the potential of bakery waste valorization in the Netherlands. As mentioned in the research, many of the bakeries that has been studied by researcher suggested digestion of waste into biogas as an alternative for dealing with losses. Further studies on biogas production from bakery waste by this research shows it could be considered as a relatively cost-effective manner regarding the sustainable financial return after return of one-off costs in investment for equipment. Further investment of a third party in facilities and employment of waste from bakeries would be considered as a more logical alternative to benefit bakeries regarding the initial investment costs.

According to previous section, selection of a manner to treat food waste, substantially depends on the unavoidable fraction of the food waste per sector in food industry. As an example due to significant avoidable food waste fraction in bakery industry, the Dutch Ministry of Agriculture in partnership with European Bakery Innovation Center carries on a project to recover the day-old bread to human food products again (Ministry of Agriculture, Nature & Food Quality, 2010).

Regarding food waste in industrial sector and their activities for food processing, the chemical components of food losses/residues and its calorific value for energy production varies per industrial sector. However specifying exact numbers on the amount of waste in industrial sector is quite difficult as the producers would not announce the detailed data and information on their wastage.

Concerning household food waste in the Netherlands, as Dutch Nutrition Center (2017) reported, the dairy products, vegetable and fruits have the highest amount of food waste in Dutch households. Discussing about household waste it should be mentioned that the food waste collection and recycling faces various complexities. For instance in the case of dairy product wastes, 43% wasted yoghurt is discarded in kitchen sinks entering the sewage system or 67% of meal as well as 37% of bread leftover are thrown away through garbage bin instead of organic waste bin which makes the recycling process harder. One fourth of food waste is disposed through sink, 35% is putted in garbage bin and 25% discarded in organic waste bin. Hence, it could be concluded that approximately 60% of the household waste has the potential of conversion into biofuel, albeit the amount of avoidable food waste must be deducted from the aggregated amount. For disposal of municipal food waste, as described in the information on Dutch Waste Management Association website[1], the operation for collection and processing of municipal solid waste is carried out by different public and private companies in different provinces and cities.

The percentage of manners in which the municipal food waste is treated (e.g. incineration, composting, landfill etc.) is addressed in section 2.2 of this research.

With regard to the food waste characteristics for valorization of household food waste to biofuel in the Netherlands, fruit, vegetable and bread residues as well as leftovers from meals residues shape the highest portion of food waste in municipal waste, look at Annex 2 (Dutch Nutrition Center, 2017). Elaborating vegetable and fruit waste as an example. Due to high hydrocarbon and fatty acid existence in elemental contents of vegetable and fruit waste, they have high potential for biofuel production or also to be

[1] www.verenigingafvalbedrijven.nl

used in processing of other biomass material for increasing the yield (Lam et. al.. 2016).

*3.1.4 Unavoidable food waste data and availability in Netherlands*

With the knowledge on theories and practical situation of food waste in the Netherlands, this section is dedicated to review the data and statistics to estimate the net amount of Dutch unavoidable food waste. After analyzing the technologies for food waste valorization in next sections, this value will be used to calculate the biofuel and bioenergy production capacity in the Netherlands.

*3.2 Total food amount waste estimation*

The data use on total amount of food waste in the Netherlands by this research is from Kretschmer et. al. (2013) from the year 2006, look at Table 5. Estimating total amount of food waste for industrial sector and household differs. Regarding industrial sector food waste, there is a lack of legitimate data in the existing. This lack of data has also been addressed in European Union research works on food waste such as Kretschmer et. al. (2013) and Monier et. al. (2010)

Estimation of total amount of food waste for household and industrial sector differs. However in order to carry on the estimations for biofuel and energy production in the upcoming sections of this work, the number 6,412 Kton would be considered as Dutch food industry wastage.

According to Kretschmer et. al. (2013) there are two remarkable data sources for Dutch household food waste. Based on Danish Environmental Ministry Food Waste Report the amount of household food waste in the Netherlands is 1,837 Kton and based on EUROSTAT report it is 1,703 Kton in 2006 (Kretschmer et. al. 2013). According to the latter mentioned research works, the average per capita food waste in the Netherlands is 108.5 kg per person according to 2006 which compared to official report by Dutch Nutrition Center (2017) which implies 47 kg household waste per person for 2010, there is a huge gap despite the difference in years of estimation. This is because of some research use the minimum scenario per capita to calculate household food waste per capita.

The minimum scenario offers a share of 8.375% food waste in municipal solid waste of European countries on the basis of observing and analyzing data from different countries. Herby, Table 3 presents the household food waste per capita in the Netherlands to track the food waste trend among Dutch households in the Netherlands.

Table 3- Approximate Dutch household food waste amount based on minimum scenario method

| **Year** | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
|---|---|---|---|---|---|---|---|---|
| **Total MSW*** | 10,061.00 | 10,163.00 | 9,816.00 | 9,446.00 | 9,517.00 | 9,512.00 | 9,510.00 | 9,539.00 |
| **HHFW**** | 842.61 | 851.15 | 822.09 | 791.10 | 797.05 | 796.63 | 796.46 | 798.89 |
| **HHFW per capita** | 50.70 | 51.58 | 49.82 | 47.95 | 48.31 | 48.28 | 46.85 | 46.99 |

*MSW: Municipal Solid Waste
**HHFW: Household Food Waste
*Note*: The population of the Netherlands for estimating HHFW per capita for the years 2010 to 2015 assumed as 16.5 million and for 2016 and 2017 assumed as 17 million.

Comparing the amounts estimated in Table 3 and the data presented by Dutch Nutrition Center (48 kg for 2010, 47 kg for 2013 and 41 kg for 2016) the numbers using minimum scenario method are in compliance with the official statistics, however the estimation for 2016 represents more than 5 kg variance between the two numbers. However in overall, comparison of estimated data with official data do not represent a huge variance (less than 5%). The next section estimates the total amount of unavoidable food waste in the Netherlands, therefore the provided data in Table 6 contributes to compare the amount estimation on unavoidable food waste to assess its compliance with Dutch food waste trends.

### *3.3 Unavoidable food waste estimation*

After clarifying the data for total amount of food waste in the Netherlands, this section estimates the amount of unavoidable Dutch food waste (secondary residues/waste) based on the theory and model discussed in section 3.1.2. Accordingly, the following formula could be used for estimating the total amount of food waste could potentially is used for biofuel production:

*Food waste/residues with potential to biofuel conversion =*
*Total amount of food waste - (Avoidable food waste + Residues / waste valorized to food & feed)*

The unavoidable food waste estimation differs per sector of consumers. For instance in the case of household unavoidable food waste estimation, De Laurentiis et. al. (2018) in their work presented detailed values (percentages) of inedible fraction of different fruits and vegetables. Hereby, an average of 15.57% of various sort of fruits and 24.08% of vegetables are considered as unavoidable waste. Table 4 shows average amount of inedible food waste for top three highly consumed fruits in the Netherlands based on 2010 fruit and vegetable consumption statistics (Geurts et. al., 2017) with the potential energy value using different technologies.

Table 4- Inedible fraction and potential calorific value of top three highly consumed fruits in Netherlands in 2010

| Type of fruit | Consumption per capita (Food Waste NL)* | Inedible fraction (De Laurentiis et. al., 2018) | Total unavoidable waste per person per year | Total waste per year (Ton)** |
|---|---|---|---|---|
| Apple | ~35 g/day | 12% | 1.53 Kg | 25,352.1 |
| Orange | ~11 g/day | 24% | 0.96 Kg | 15,907.2 |
| Banana | ~18 g/day | 35% | 2.30 Kg | 38,111 |

*The consumption of popular fruits has been estimated for women between age of 7-69 years old in original report. Here it has been assumed the mean consumption of the selected fruit is similar for men.
** Population of Netherlands considered as 16.57 million in 2010 based on CBS data[2].

In the case of estimating food waste in industry and food processing sector, Monier et. al. (2010) presented a table for food wastage in different industrial processes. As an example for butchery industry, which is the second largest food industry in the Netherlands after bakeries with 315 active industrial units (CBSStatLine, 2018), the unavoidable fraction for pig slaughtering is 35% and this number for beef slaughtering is between 40 to 52 percent (Monier et. al., 2010). In this case, animal By-Product Regulation of European Commission (1069/2009/EC), only allows some certain disposal routes in which conversion to biofuel could be considered as a suitable alternative (Ware & power, 2016).

[2] https://opendata.cbs.nl/statline/#/CBS/en/dataset/37296eng/table?ts=1535746880467

Estimating total unavoidable food waste amount using the mentioned methods for household and industry however provides a more accurate and exact estimation on food waste in the Netherlands but because of lack of legitimate data on detailed consumption of various foods and scientific reference for their inedible fraction and also industrial waste/residues, it would be problematic to employ it in this research. Instead this research uses the average unavoidable food waste for each step of the food supply chain presented by a report in a European Union research project about food waste (Stenmarck et. al., 2016).

Table  represents the standard percent of unavoidable (inedible) food waste within each step of food supply chain excluding agricultural processes (agro-waste). Herby, in primary production and food processing steps nearly 50% of losses are unavoidable and so 17% of food waste by wholesalers and retailers, 39% of loss by different food services, restaurants and catering as well as 40% of household food waste is also inedible.

Table - Average percentage of unavoidable food waste per step of production in EU countries using different year data (Source: Stenmarck et. al., 2016)

| **Food production stage** | Primary production | Processing | Wholesale & retailers | Food services & catering | Household |
|---|---|---|---|---|---|
| **Unavoidable waste (%)** | 50% | 50% | 17% | 41% | 40% |

In this research only the urban food waste (incl. household, restaurants/catering services) would be taken into account as a sample to estimate the potential of its conversion into biofuel. The reason industrial food waste is not considered in this estimation is that the further processing for industrial food waste is highly variant based on different industrial unit activities in food waste industry so that different streams for valorization of industrial food waste could be assumed based on waste ingredients and different companies’ waste treatment plans. Further as mentioned before, vividly there has been a lack of data for industrial sector food waste in the Netherlands according to the literature and reports.

Thus, considering the amount of food waste by different sectors in Table 6 and using the percentages for unavoidable food waste for each sector in Table 5, the total amount of food waste that could be considered as secondary resource and be consistently used for conversion to energy is estimated as in Table 6. Compared to Table 3 and what have been discussed in Section 3.2 these numbers seem rational. Therefore, the waste and residues in manufacturing processes of food supply chain and afterwards the household food waste have the highest amount of food waste with potential for conversion to biofuel.

Table 6- Total and unavoidable food waste amount and percentage per sector in Netherlands in 2006 (Source: Kretschmer et. al., 2013)

| **Food supply chain sector** | **Production & processing** | **Household** | **Retailer & wholesaler** | **Food service & catering** | **Total** |
|---|---|---|---|---|---|
| Total amount in (Kt) | 6, 412 | 1,838 | 145 kt | 446 kt | 8,841 |
| Unavoidable waste (Kt) | 3,206 | 735.2 | 24.65 | 182.86 | 4,148.71 |

Concerning Table 3 and Section 3.1.2 only secondary residues and waste from food could be used for biofuel production. In Section 2.2 it has been mentioned that 54.6% of total amount of food waste in the Netherlands is incinerated. With these regards the total amount of municipal unavoidable food waste in Table 6 that is classified as secondary residue is 418.63 Kton. For this number it should also be taken into account that according to Dutch Nutrition Center (2017) approximately 60.2% of the food waste is discarded in Vegetable, Fruit & Garden (VFG) and residual bins which could be collected and valorized to biofuel and the rest are disposed by routes such as kitchen sink and could not be valorized. Therefore assuming the same percentage of solid food waste discard by restaurants and catering services through the residual bins, the net amount of municipal food waste with potential of valorization to biofuel in the Netherlands is 252.01 Kton. As mentioned before, this number will be used in further estimations for biofuel and bioenergy production capacity from food waste in the Netherlands.

## CHAPTER IV

## FOOD WASTE VALORIZATION: STEPS AND TECHNOLOGIES

The background and data provided with the previous parts of this research are used in the current chapter to estimate capacity and potential of biofuel production from food waste in the Netherlands. At the first place the processes and steps within the biofuel production from food waste is discussed. Next, different technologies for doing so, as the most significant resource in food waste based biofuel production will be reviewed and analyzed. The findings and results of this chapter leads to discussing the extent of food waste conversion to biofuel feasibility. Lastly according to the theories, Dutch bioeconomy agenda and estimated data and the results derived from technology analysis, this chapter answers the first sub research question and the part of main question about conversion of food waste to biofuel feasibility.

### *4.1 Food waste based biofuel value chain*

A value chain model explains all the activities in different phases of production and delivery of a product or service. Value chain includes the input material for production and their inbound logistics, production operations and equipment for it, outbound logistics, marketing/sale and after-sale services.

The reason to use the value chain model to study the steps and processes for biofuel production from food waste is that this model also provides a clear clue about crucial resources in these processes. Identification of the most important resources contributes to understand what resources in food waste based biofuel production is the most crucial for the feasibility. This will be useful for studying feasibility -in the sense of finding the critical step or resource that needs higher attention and finances- as well as analyzing policies and strategies an policies on this basis.

According to the steps has been previously described for food waste conversion into biofuel, Figure 4 shows a simplified schematic view of the food waste based biofuel value chain and the relevant steps and required resources.

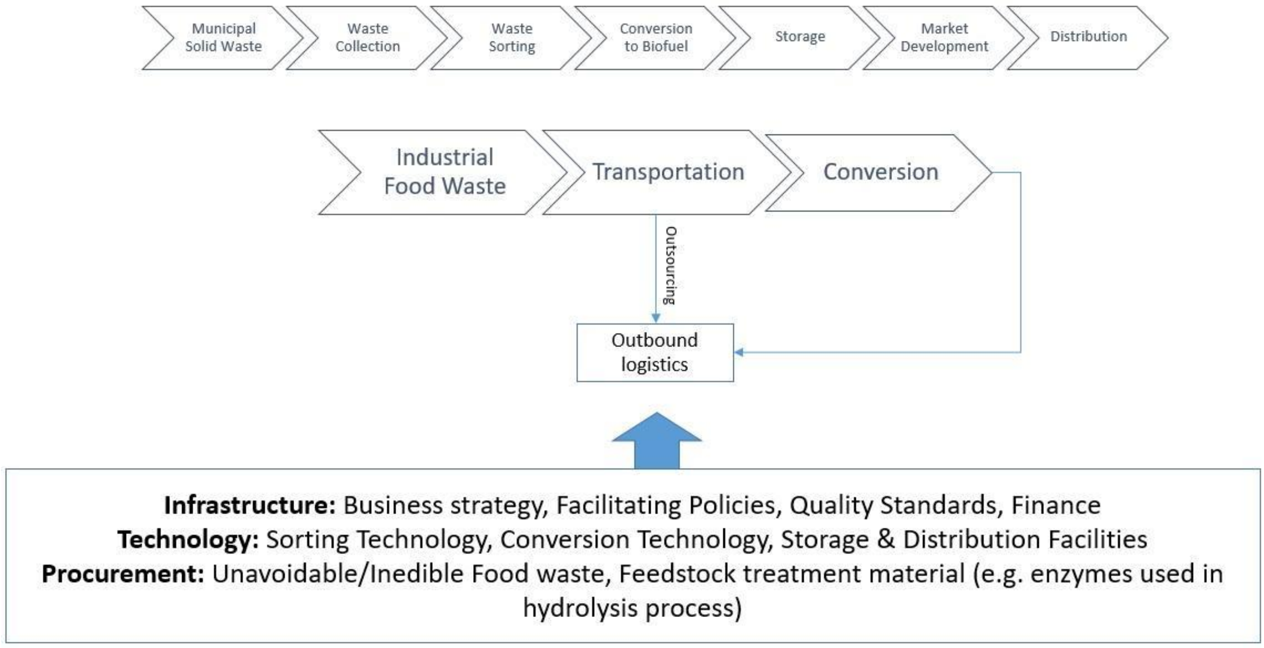



Figure 4-Value chain model for production of biofuel from food waste

de Jong et. al. (2017) in their work presented three different strategies for biofuel production supply chain as shown in Figure 4. Applying these supply chain methods to production of biofuel from food waste in municipal solid waste, the feedstock are food waste collected from household and the waste sorting centers play the role as pre-treatment units. In this context, the distributed hub-and-spoke supply chain method is an appropriate strategy which is more close to the real world situation in the Netherlands as collection and treatment of food waste is done by local municipalities.

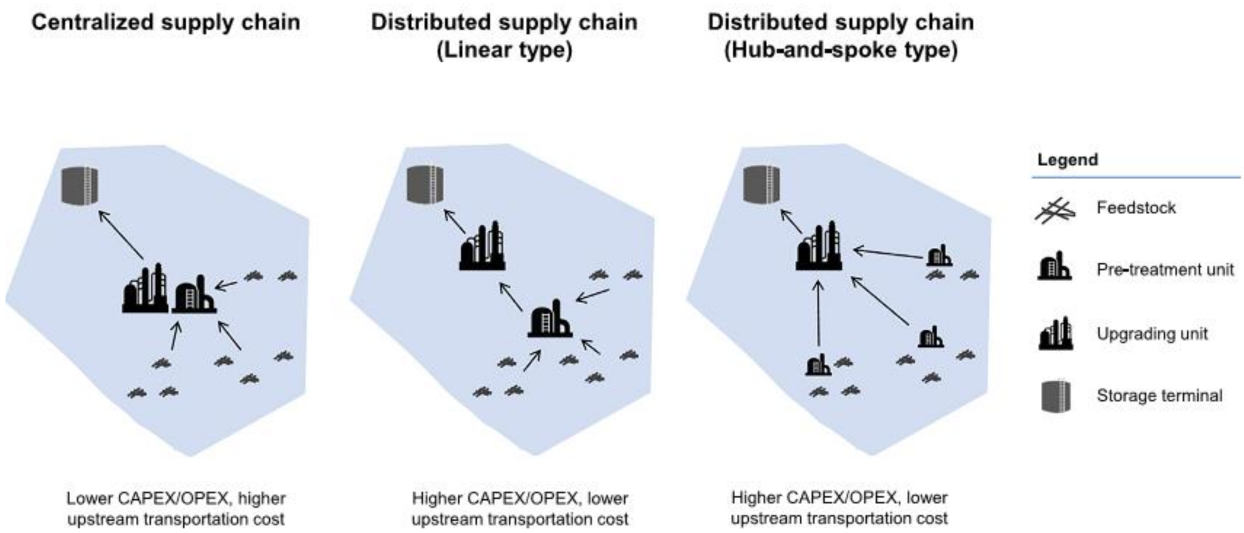



Figure 5- Comparing different supply chain models for biomass production (Source: De Jong et. al., 2017)

The supply chain model for food companies contains more complexities and depends on their strategy for dealing with their waste. In the case they establish installation to convert their own west (e.g. an anaerobic digestion system) it reduces transportation cost and imposes the capital and operating expenses, while outsourcing entails transportation and contract costs and instead cuts the costs for technology adoption, operations and maintenance.

Hereby it could be concluded that technology is the most significant resource which is definitive in supply chain costs and production capacity of biofuel production from food waste. So that the next section of this chapter discusses different aspects of technologies for food waste conversion to biofuel.

### *4.2 Technologies for food waste conversion to biofuel*

The first step in studying the technologies for food waste conversion to biofuel is grasping a general insight on the existing technologies from food waste conversion to biofuel. Further, this section discusses that to what extent these type of biofuels are useful in the Netherlands and who are the consumers. Thereupon knowing the extent of food waste based biofuel demand as well technology prospects, the capacity biofuel production from food waste using different reviewed technologies will be presented. This provides a measure to compare food waste based biofuel extent of feasibility and contribution to Dutch bioeconomy targets mentioned before.

The technologies for conversion of food supply chain waste to bioenergy could be divided in two main categories: Biological and Thermochemical technologies. The examples of biological methods are anaerobic digestion for biomethane production and biohydrogen production as well as fermentation to produce bioethanol. On the other side thermochemical technologies such as pyrolysis, torrefaction and Hydrothermal Carbonization (HTC) are used to produce char and other by-products. The by-products usually contains bio-liquids and low calorific value biogas which could be used for industrial activities (Pham et. al., 2015). In the following, this section reviews different technologies in the context of the type of biofuel produced by them. The numbers for calorific values and other conditions in converting food waste to biofuel with respect to different methods will be used by this research to estimate potential biofuel and energy production.

### *4.2.1 Food waste to biogas technologies*

**Methane production:** Producing methane from food waste by means of a single-stage anaerobic digestion is known as a reasonable option and is used by several industries and municipal waste treatment plants in a large scale in different countries. As an example in the Netherlands, Biocel anaerobic digestion and composting plant in Lelystad is capable to produce 8.4 m3 biogas per 1000 kg organic waste. However most of the waste in this plant is used for composting (Goossensen, 2017).

The process in anaerobic digestion requires several days (depending on the technology normally between 30 to 120 days) (Pham et. al., 2015). Therefore when using this method for food waste conversion, deployment for storage of waste before its digestion should be taken into account.

Anaerobic digestion could be done using wet or dry digesters, the problem for food waste conversion to biogas using anaerobic digestion is the high water content in food waste which negatively affects the biogas yield.

According to the literature, the average methane (CH4) yield from food waste digestion is around 0.450 m3/Kg for different technologies with efficiency of 80% to roughly 90% if there is a pre-treatment process. (Kiran et. al., 2014; Khalid et. al., 2011). The digestion process using a single-stage technique as presented in Zhang et. al. (2007) needs approximately 28 days to be completed. The higher calorific value of biomethane which will be used in further calculations is approximately 39.5 MJ/m3. To estimate the biofuel and energy potential by this method it should be borne in mind that municipal solid waste. According to the literature it could be said that in most of the cities household food waste contains between nearly 75% moisture rate (Veeken et. al., 2005; Zhang et. al., 2007). This number will be used as water content of food waste in calculating food waste based biofuel production capacity using other dry technologies in this research.

**Hydrogen production:** Using multiple-stage anaerobic digestion (two stage digestion in this case) method yields both methane and hydrogen or hythane gas. However the technical complexity and costs for multiple-stage digestion is higher than single-stage digestion which is recognized as a simple method. Mixed methods could also be used to produce hydrogen gas which contains high calorific value, albeit due to economic and technological difficulties for purification, storage and distribution of hydrogen it is now recognized as being a feasible method so far (Kiran et. al., 2014). It must be mentioned about the energy production from hydrogen, however H2 has a rich calorific value but the density and yield using most of methods is low (Zhou, 2005).

For hydrogen production from wet food waste in municipal solid waste the yield has been estimated around 0.152 M3/Kg Volatile Solids (VS) (Jarunglumlert et. al., 2017). Further the amount of volatile solids in a mixed food waste could be estimated around 85% (Kubaska et. al., 2010). According to Kiran et. al. (2014) for different technologies and processes to produce biohydrogen from food waste, the highest yield of 0.160 m3/Kg VS could be considered using a leaching bed reactor. However the working volume of this sample is quite low but this number would be used in this research for calculating hydrogen yield from Dutch food waste. The duration for processing food waste to hydrogen using this technology requires nearly 7 days. Further the calorific value of hydrogen will be considered 12.5 MJ/m3 in further calculations.

### *4.2.2 Food waste to bioethanol*

To produce ethanol process of hydrolysis to break down the feedstock to their sugar molecules and fermentation is necessary. Using food waste as feedstock for ethanol production does not require a hard pre-treatment step in most of the cases (Kiran et. al., 2014). On a laboratory scale two different methods of Separate Hydrolysis and Fermentation (SHF) and Simultaneous Saccharification and Fermentation (SSF) has been employed to study feasibility of ethanol production from a mix food waste sample. The ethanol yield using SHF evaluated as 0.43 kg ethanol/kg total solids, this value using SHF calculated nearly 0.31 g/ethanol/g total solids (Kim et. al., 2011). However this amount of ethanol yield is based on laboratory situation. Comparing samples in large scale for bioethanol production from food waste the mentioned number is quite high. As example for conversion of food waste to bioethanol in large scale in Japan, the ethanol yield per kilogram of dry food waste is 47.10 kg, herby considering 0.2 kg ethanol per kilogram of dry food waste is a rational number (Kiran et. al., 2014). Despite this, having a futuristic view, the mentioned numbers from the research by Kim et. al. (2011) will be considered in calculations in next steps of this research.

*4.2.3 Thermal processes for biochar production*

**Torrefaction:** This technology is used for upgrading biomass to second generation of pellets which is more energy-efficient and cost-efficient (Kiel et. al., 2009). The potential for conversion of food waste to biochar by means of torrefication has been studied by Pahla et. al. (2018). Accordingly, at the optimum point of process temperature (275 C) the higher calorific value for food waste has been upgraded to 26.155 MJ/Kg from 19.76 MJ/Kg of dried food waste. The mass yield has been estimated between 60 to 70% for dried sample of food waste.

Regarding torrefaction commercialization, during the last decade this technology has been rapidly improved from being in R&D phase to the stage of market introduction (Koppejan et. al., 2012).

**Pyrolysis:** Regarding to different methods in pyrolysis, slow pyrolysis yields more char than fast and flash pyrolysis. In slow pyrolysis process there will be relatively equal percentage of char, oil and gas yield (Jahirul et. al., 2012). In a study by Lee et. al. (2018) the higher calorific value of biochar yielded from food waste pyrolysis has been measured around 24.33 MJ/Kg which is comparable with calorific value of woody biomass with 44% biochar yield.

**Hydrothermal Carbonization (HTC)**: This technology is more suitable for homogenized food waste to produce hydrochar. This technology has been experimented for mixed wet food waste by McGaughy & Reza (2018) to produce hydrochar and other liquid and gaseous by-products. With respect to the results, HTC could yield a mass and higher calorific value from 68.5% mass yield with higher calorific value of 33.08 MJ/Kg energy to mass yield of 75% by higher calorific value of 30.45 MJ/Kg.

Concluding the section 4.2, Table 7 presents a summary of the characteristics as well as technological consideration of the food waste based biofuel produced using the reviewed technologies. The first column in the table contains the reviewed technologies by which food waste is valorized to biofuel. The second column summarizes the amount of biofuel yield per kg of food waste as well as the technological considerations for this. As an example using anaerobic digestion for biofuel production from volatile solids in the food waste yields in 0.450 m3 per kilogram of food waste with 85% efficiency. For torrefaction, the amount of yielded biochar is 65% of the total dried amount of food waste.

Table 7- Yield amount, energy value and technological considerations of food waste based biofuel production using different technologies*

| **Conversion Technology** | **Biofuel Yield** | **Higher calorific Value** | **Phase in technology life cycle** | **References** |
|---|---|---|---|---|
| SHF | 0.47 Kg ethanol / Kg FW | 26.7 MJ/Kg | R&D** | Kiran et. al. (2014); Kim et. al. (2011) |
| SSF | 0.31 g ethanol / Kg FW | 26.7 MJ/Kg | | Kiran et. al. (2014); Kim et. al. (2011) |
| Anaerobic digestion | 0.450 m3 biomethane / Kg VS | 39.5 MJ/m3 | Relatively mature | Kiran et. al. (2014); Khalid et. al. (2011) |
| Fermentation to hydrogen | 160 m3 Hydrogen/Kg VS | 12 MJ/m3 | R&D | Kiran et. al. (2014); Jarunglumlert et. al. (2017) |
| Torrefaction | 65% of dried FW | 26.155 MJ/Kg | Ascent | Pahla et. Al. (2018) |
| Pyrolysis | 44% of dried FW | 24.33 MJ/Kg | R&D | Lee et. al. (2018) |
| HTC | 71.75% of total FW | 31.76 MJ/Kg | R&D | McGaughy & Reza (2018) |

*FW: Food Waste amount, SHF: Separate Hydrolysis & Fermentation, SSF: Saccharification and Fermentation
** The existing technologies for large scale production yield lower amount of bioethanol
***VS assumed as 85% for both anaerobic digestion and hydrogen production using fermentation

Third column represents the higher calorific value for the biofuel produced from food waste and the next column shows the phase of technology life cycle in the sense of to what extent this technology is mature to be implemented in a large scale. As Table 7 represents most of the technologies are in R&D phase and more research is required to introduce them to the market. In the case of anaerobic digestion and torrefaction, as mentioned before there are some limited commercialized activities to convert food waste to biofuel using these methods.

### *4.3 Biofuel production estimation from food waste in Netherlands*

Using the estimation of Dutch unavoidable food waste in household level and the information on technologies to produce biofuel from food waste leads to estimating the capacity of biofuel and energy production in this section. These values are presented in Table 8.

Table 8- Potential biofuel and energy production value from food waste in the Netherlands

| **Technology (biofuel type)** | **Biofuel production (Unit)** | **Energy yield (PJ)** |
|---|---|---|
| SHF (bioethanol) | 29,611.18 ton | 0.791 |
| SSF (bioethanol) | 19,530.78 ton | 0.521 |
| AD* (Biomethane) | 24,098.46 m3 | 0.952 |
| Hydrogen fermentation (Biohydrogen) | 8,568.34 m3 | 0.103 |
| Torrefaction (Biochar) | 40,951.63 ton | 1.071 |
| Pyrolysis (Biochar) | 60,203.00 ton | 1.465 |
| HTC (Hydrochar) | 180,817.18 ton | 5.743 |

*AD: Anaerobic Digestion

The amount of unavoidable food has been assumed 252.01 as Kton as calculated in Chapter 3. To reach the values in second column of Table 8 the values for biofuel yield per kg food waste (second column Table 7) multiplied with 252.01 Kton unavoidable food waste. Subsequently, the energy yield is estimated by multiplying values from biofuel production and calorific value of different biofuels from column three in Table 7. In this manner, there are more consideration as will be explained in the following lines.

For calculating the biofuel production amount in second column of Table 8, the dried content of food waste has been taken into account. As mentioend before, in this research the wet content of food waste is assumed as 75%, so that the dried content of food waste is considered 25% of the total amount. Calculating the hydrochar using HTC method was excluded from this assumption as this technology could process wet content of food waste. For this reason the energy yield using HTC method represents a higher value compared to the other technologies.

*4.4 Food waste based biofuel consumption in Netherlands*

This section is dedicated to study the consumption porpuses of biofuels produced from food waste in the Netherlands. Chapter 2 of the present research has conceptualized the importance of using sustainable biomass and biofuel in order achieve the targets in sustainable bioeconomy plans. To this extent, this section reviews the usefulness of biofuels produced from food waste with regard to Dutch biofuel consumption situation and data.

Figure 6 shows the summarized data on production of bioenergy using different sources of biomass (look at Annex 3 for more detailed data). Despite the biomass used for incineration, the production of bioenergy using biomass in household represents the highest number energy production by biomass. According to the data in Annex 3, the biomass consumed by household for heat production. In Chapter 2 it has been addressed that a big part of woody biomass -which is also used by household for heat production- is imported. The biochar produced from food waste could be a considered as an alternative to satisfy part of the demand for biomass stoves in houses and companies.

Due to the mentioned target in Chapter 2 for production of 7.5 PJ bioenergy in the scenario of coal-firing plants closure, biochar could also be used for production of combined heat and power to reach this target.

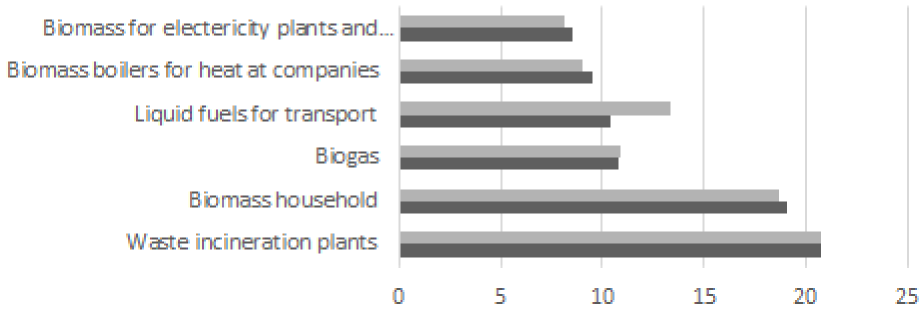
Regarding biohydrogen consumption, it has a relatively a large market in the north of the Netherlands. Particularly, the Northern Innovation Board in the Netherlands has estimated that during the years 2017 to 2030 nearly 270 Kton hydrogen for production of 38 PJ energy will be consumed. Hydrogen in this region is used for purposes of mobility, grid balancing and also by chemical industries to produce ammonia and methanol. However most of this hydrogen is supplied from wind power plants (van Wijk, 2017).

Biomethane is mostly used for production of electricity and heat. As an example, the process of anaerobic digestion has been used to develop a district energy system in the municipality of Zeewolde in Flevoland in Netherlands. This project supplied nearly 0.05 PJ energy for the mentioned municipality. Production of biogas for consuming as in district heating is an attractive option due to production capacity of biogas from food waste (IEA, 2011).

Bioethanol is generally used for blending with transportation diesel. Production of bioethanol and biodiesel products, however contributes for achieving the biofuel blending target (see Section 5.3.2) in transportation, but the market for this product seems limited regarding the its viability with Dutch transportation system. Moreover discussing the case of bioethanol, there is a limit of no more than maximum of 5% ethanol blend in the biofuel content (van Grinsven & van Essen, 2015). With respect to high amount of biodiesel that is produced in the Netherlands and exported, this product does not seem to have a high demand (Goh & Junginger, 2015).

### *4.5 Discussion and conclusion*

This section discusses the results and findings derived from the previous sections concerning the data and theories in other chapters. By doing so, the first sub-question and part of the main research question about feasibility of biofuel production from food waste will be answered.




| PJ | Waste incineration plants | Biomass household | Biogas | Liquid fuels for transport | Biomass boilers for heat at companies | Biomass for electericity plants and companies |
|---|---|---|---|---|---|---|
| 2015 | 20,71 | 18,64 | 10,87 | 13,32 | 9,03 | 8,12 |
| 2016 | 20,73 | 19,04 | 10,8 | 10,44 | 9,49 | 8,53 |

Figure 6- Renewable energy consumption from biomass sources in the netherlands (Source: CBS database, 2018)

It has been mentioned in Section 2.2 that Dutch government plan to shut down the coal-firing plants by 2030 is a step toward bioeconomy. Further disincentives for incineration such as incineration tax and policies to minimize incineration is another step to steer stepping toward bioeconomy in a sustainable framework -considering the environmental issues of incineration (look at section 5.2.2 for more details on incineration tax). The measure to assess the extent of biofuel production originated from food waste in the context of Dutch bioeconomy targets is achieving 7.5 PJ bioenergy production by 2030 to meet the goal for compensating the energy (and electricity) capacity produced by coal.

As the results of energy yield in Table 8 shows, the produced volume of char from food waste using thermal methods seems to have more potential in order to contribute for achieving 2030 bioenergy target. This number for hydrochar produced by HTC method is significant, namely using this method to produce hydrochar could could potentially contribute to fulfil 76.5% of this target by only using unavoidable household food waste in the Netherlands. Further the char volume produced by this method is nearly 0.18 Mton. Comparing it with wood pellets import amount to the Netherlands in 2012 that is 0.89 Mton (Goh & Junginger, 2015), hydrochar from food waste could reduce wood pellets import by 20%.

However it must be borne in mind that HTC technology is not yet a mature technology that is commonly used in large scale and production of this numbers of hydrochar and bioenergy from food waste is more of a long-term solution regarding technological considerations and its feasibility. Regarding the short-term solutions and alternatives for treating food waste in order to step toward the targets in Dutch bioeconomy plan, using methods such as anaerobic digestion are more practical and feasible in a small scale due to its low biogas production capacity compared to total biogas consumption volume as presented in Figure 7. Due to Section 4.4 there are successful examples such as using waste digestion for district heat and electricity production in Zeewolde municipality. This could be a pattern to develop community based bioenergy production using food waste based biogas. Particularly, this model is economically suitable for small municipalities as it employs a centralized bioenergy supply chain model in a small scale (look at Figure 5 in Section 4.1) which includes lower capital expenses (CAPEX) and operating expenses (OPEX).

The previous section has also addressed some examples of hydrogen consumption in northern part of the Netherlands. With the hydrogen production potential using the existing technologies. It does not seem to be an economically feasible option unless there would be a specific niche market for it. For instance in the municipality of Delfzijl in Groningen province, there is a project going on since 2017 to use hydrogen vehicles for public transportation (van Wijk, 2017). However the feasibility and productivity of hydrogen produced from food waste should be compared to other alternatives for producing hydrogen in different specific cases.

According to what have been discussed in this section, conversion of food waste to biofuel seems to be a feasible solution for achieving Dutch bioeconomy targets in long-term rather than short-term. The most important factor that leads to feasibility of biofuel production from food waste is technology development. One barrier in the manner of food waste based biofuel production is high costs of technology. Therefore it is required to make policies and strategies for facilitating production of biofuel from food waste in the manner of achieving bioeconomy targets such as the 2030 target that has been discussed before. Further, production and consumption conditions and feasibility of some biofuels such as bioethanol depends on policies and regulations such as blending obligation. Therefore the next chapter  reviews and analysis policies and strategies that contribute for facilitating production and consumption of food waste based biofuels.

# CHAPTER V

# FOOD WASTE BASED BIOFUEL: STRATEGY AND POLICY PROSPECT

This chapter is structured in 4 sub-sections to answer the second sub-question and subsequently the second part of the main research question. For this purpose, first the relevant European policies to biofuel production from food waste is reviewed. Further, the policies targeting production and consumption of food waste based biofuels are reviewed in different sections and lastly a this topic will be concluded by answering the research question. Lastly the fourth section discusses how these policies could facilitate food waste based biofuel producing and using food waste based biofuels.

## *5.1 European Union policy context*

Discussing the European regulation and legal framework on food waste, formerly the policy and regulation about food waste management mostly dealt with the waste disposal and landfilling. Examples of such policies are the European legal frameworks for waste disposal Directive (75/442/EEC) and also Directive (75/442/EEC) about municipal solid waste landfilling. Both of the mentioned legal framework alongside some other frameworks for food disposal and landfilling focus on reducing the landfilled waste and consequently prevent the caused problems waste disposal. Related to this research, by operating a permit system on landfill sites, article 5 of landfill directive (1882/2003/EC) emphasizes on reduction of biodegradable wastes to be landfilled.

The most recent European waste framework directive (2008/98/EC) of food waste drew a new approach in waste management for the countries in European Union. This directive steps beyond only landfill prevention and concentrates more on recycling the waste. Therefore, it presents new requirements for bio-waste treatment in the member states. The three major pillars of this directive are: separation of bio-waste, bio-waste treatment with least environmental impacts and production of products out of bio-waste. To this extent, the member states of the European Union are obligated to put a national food waste plan in action in order to comply with the European Union regulation. This plan should also include activities and incentives for producing bioenergy from food waste.

Dutch regulation has been aligned with European Union rules and policies on sustainable bio-based economy and biomass development to satisfy European targets as well as standards for sustainable biomass production. In this manner there are other policy schemes to facilitate food waste conversion into biomass. These policies and regulation are reviewed in the following in this chapter.

### *5.2 Policies and strategies to facilitate Production*

#### *5.2.1 Market based instruments*

As mentioned before, there is no national scheme to tackle food waste issue. However there are some market-based instruments as incentives and disincentives to deal with food waste problem.

A funding scheme called Small Business Innovation Research (SBIR) is offered by Netherlands Enterprise Agency (RVO) as an incentive to support innovative ideas for food waste reduction and also transforming food waste to useful production including biofuels. This scheme supported ideas for dealing with food waste

Throughout different stages of food supply chain from harvesting to retailing and catering services (Aramyan & Velva, 2016).

MIT-regeling Topsector is another fund scheme to stimulate innovative research in different topics of agro-food industry (not specifically food waste issue). There are two topics out of 11 covered topics within this fund program that addresses green input valorization and resource efficiency in a broad scope which also could include food waste valorization.

In addition to the mentioned schemes, currently there is two tax schemes aim at reducing the costs for employing environmentally friendly assets by a tax reduction scheme. Namely MIA (Milieu Investeringsaftrek - Environmental Investment Rebate) and VAMIL (Willekeurige Afschrijving Milieu-investeringen - Arbitrary depreciation of environmental investments). In relation to food waste conversion production, the list of assets that are qualified for tax reduction scheme includes "Biofuel Production Plant (Code in environmental list: 251205)" (MIA/VAMIL, 2018). In the light of boosting bio-based economy as well as circular economy, these incentives could be used to motivate companies for using alternative biofuels. Specific

*5.2.2 Incineration and landfill tax*

Landfill tax in the Netherlands which introduced in 1995 and later reintroduced in 2015 is another indirect instrument to motivate involved parties in food waste for recycling. In the new scheme considers 13.1 euro per ton of landfilling and incineration in 2017. However the price for landfilling tax in the Netherlands is one of the lowest among EU Union countries, but with 2-3% of total waste amount landfilling, Netherlands is one of the most successful countries in Europe (Aramyan & Velva, 2016; Lieten & Dijcker, 2018), albeit this is owing to high amount of waste incineration as mentioned before.

Furthermore, Dutch government are planning to minimize the share of incineration of organic waste. These policies facilitates achieving a sustainable bioeconomy. Two specific example are the VANG (Van Afval Naar Grondstof- From Waste to Resource) which introduces the ambition of reducing incineration by 50% as well a tax scheme has been imposed on incineration from April 2014 (Bastein et. al., 2013).

*5.3 Policies and strategies to facilitate consumption*

*5.3.1 Certification*

Certification of biomass, likewise any other certificate, is a seal dedicated by an independent third party proving that the biomass meets different standards. Certification mostly deals with the sustainability aspect of biomass. In this manner, ensuring the sustainability and quality of biomass/biofuels contributes for attracting more consumers in the market.

The sustainability criteria of biofuels has been presented by European Union as in the Renewable Energy Directive (RED) and the Fuel Quality Directive. The European regulation mostly concentrates on imported biomass material sustainability aspect. Hence there are several regional certificate schemes by both governmental buddies and private organizations (biomass selection). As it comes to food waste and residues, for certification from residues most of the certification schemes have less strict rules but meanwhile they are protective for not using and or compete with food production as biomass. Therefore as discussed in chapter 3, it must be considered to use unavoidable secondary residues without potential for valorization into human of animal food and feed for biofuel production.

Currently there are various certification schemes that are commonly used in the Netherlands such as NTA 8080 which is recognized by European Union as a voluntary scheme to ensure the sustainability requirements of the various types of solid, liquid and gaseous biomass that are used for bioenergy production. The scope of this certificate includes almost entire biomass production from origin of the primary biomass resource to valorization and takes detailed aspects of social and environmental sustainability into account. There are also other schemes which are also categorized as voluntary certificates such as ISCC and 2BSvs (Goh & Junginger, 2015).

*5.3.2 Blending obligation*

The EU energy and climate change package contains using a minimum of 10% renewable energy by transportation sector in EU countries that must be achieved by 2020. Further EU Union's RED directive introduced a GHG saving strategy to ensure environmental sustainability of biofuels consumed in Europe. Hence, the biofuel produced after from 2018 onwards by installations established before 2017 must the standard of 50% GHG saving compared to fossil fuels. This number for installations established after 2017 is 60%. The Netherlands mandates an overall 7.75% renewable content in produced biofuels which has been increased to 8.5 in 2018 and will reach to 10% by 2020. The blending obligation provides an opportunity for considering organic waste as an alternative for achieving the blending target (Lieberz, 2017; van Grinsven & van Essen, 2015).

*5.3.3 Double counting of biofuel from residues and waste*

In order to achieve the blending mandate and GHG saving targets of European Union stated in RED directive the double counting rule has been introduced for biofuel produced from different type of waste and residues. This rule doubles the share of biofuels produced from residues and waste in blending target. Currently the Netherlands is implementing this scheme. Double counting also contributes for preserving the food corps from being used as biomass and also stimulates production of advanced biomass. To this extent using waste stream as input for biofuel production would be counted double which provides an incentive for consumers to use biofuels that have double counting certification (van Hasselt, 2013).

*5.4 Discussion and conclusion*

After reviewing the policies that facilitates production and consumption of food waste based biofuels. This sub-section aims at answering the second sub-question by analyzing how the existing policies could be positioned in the context of biofuel production from food waste to facilitate its production and consumption regarding other situations and considerations in production of such biofuels that has been discussed throughout this research. In this manner there are three remarks as follows:

1. **Unavoidable food waste definition and criteria for assessment:** According to Dutch Development Cooperation policy on food security, production of biofuel from food waste should not compete with human and livestock food/feed and be in conflict with soil fertilizer production (Achterbosch et. al., 2013). In order to convert food waste into biofuel, the first step is defining certain standards on type of food waste that could potentially be labeled as unavoidable and be used for conversion into biofuel. The priority for utilization of food waste follows the Moerman ladder. Thereupon, there must be clear standards for assessment of food waste sorts and specification of food waste that could be considered as secondary residues/unavoidable loss for biofuel production. This could be done with regard to some policies from European Commission policies such as (1069/2009/EC) for animal waste treatment -as an example. Assessment of type of food waste that could be used as biofuel feedstock could also be done by developing specialized certificate schemes with regard to current certification systems that reviewed earlier. Having an assessment framework also facilitates certification of food waste based biofuels and increases the motivations for consuming this type of biofuel.

2. **Bio-waste separation:** As mentioned in chapter 3, nearly 35% of Dutch household food waste is not separated and discarded in residual bins. It has also been addressed earlier in this chapter that EU waste framework directive (2008/98/EC) emphasizes on separation of bio-waste within European Union

countries. Discussing municipal organic waste -which includes food waste as well- household organic waste disposal manner and waste dividing behavior would influence the municipal organic waste pre-treatment and sorting step complexity and costs. Therefore it would be helpful to provide facilities and incentives by means of public campaigns to raise awareness in different municipalities to divide the food waste in separate bins to make the process of household food waste easier.

3. **Market-based incentives:** Regarding the policies to stimulate the research on technologies as well as financing operation and equipment and motivating different stakeholders, there are policy schemes that contribute for facilitation of food waste conversion to biofuel. In the previous section, different policy platforms such as SBIR, MIT-regeling Topsector, MIA and VAMIL has been introduced.

   Reviewing these policies it has been understood that however they provide opportunities for production of biofuel from agro-food residues, but they do not specifically categorize food waste valorization to biofuels as a topic covered in their scope. Adding food waste valorization to biofuel as a topic and category in the scheme of current platforms opens a new route to introduce food waste based biofuels to the market. As an example, MIA and VAMIL policies, in the document containing Dutch 2050 circular economy targets (Parliamentary documents II, 34 300 XII no. 27 in 2016) it is stated:

   *"The Netherlands Enterprise Agency (RVO) is currently shedding light on how existing instruments such as MIA/VAMIL can be geared to circular innovations. It is also exploring the advisability of schemes aimed at the circular economy that promote the reuse of renewable and recyclable raw materials"*

   In this context, concentration on conversion of food waste to biofuel could be considered as a circular innovation in the scheme of MIA/VAMIL policy to achieve advancement in using renewable and recyclable material.

# CHAPTER VI
# CONCLUSION

This research studied theoretical, technological and policy aspects of food waste conversion to biofuel and its feasibility in the Netherlands. According to the theoretical frame of bioeconomy, it is necessary to ensure that a bioeconomy model is sustainable. In this manner, biomass sustainability is supposed as an important pillar of a sustainable bioeconomy model.

Taking into account that Netherlands is limited on wood resources for biomass production has the highest amount of food waste per capita in Europe, using food waste as a bioresource for production of biofuel in the Netherlands contributes for achieving a sustainable biofuel resource as well as dealing with food waste issue. However it is questionable that to what extent is it feasible to convert food waste to biofuel in the Netherlands and what policies are required to facilitate it.

The extent of biofuel production from food waste in this research has been measured by comparing food waste based biofuel production capacity with a scenario for production of 7.5 PJ bioenergy using biomass after closure of coal-firing plants in 2030 in the Netherlands.

To meet sustainability criteria in production of biofuel from food waste, it must be noticed that only unavoidable food waste which consists of inedible fraction of food could be converted to biofuel. The amount of unavoidable food waste for Dutch household has been estimated approximately 252.01 by this research.

In order to convert household food waste to biofuel costs for organic waste technology has been recognized as a definitive factor in costs and productivity of biofuel from food waste. Most of the technologies for biofuel production with regard to food waste are still in R&D phase. Hydrothermal Carbonization technology (HTC) presented the highest potential by yielding 180,817.18 ton hydrochar with potential of 5.74 PJ bioenergy. This amount could decreases wood pellets import by 20% and also contribute to satisfy 76.5% of the target for production of 7.5 PJ bioenergy by 2030 compensating for the scenario of coal-firing plants closure. However whereas HTC technology requires more development, producing hydrochar from food waste in big scale could be regarded as a feasible solution in long-term. In short-term, investing more mature technologies such as anaerobic digestion in a small scale for district heating is more reasonable.

Discussing the policy aspect, firstly it is necessary to create specific standards and rules to explicitly assess what kind of food waste could be used as biofuel feedstock. Further there should be incentives and motivations for bio-waste separation in alignment with European Union waste framework directive (2008/98/EC). Moreover it has been noticed that most of the incentives for sustainable biofuel production, indirectly target food waste valorization into biofuel, in order to develop the market awareness as well as achieving sustainable bioeconomy targets, food waste conversion to biofuel could be introduced in the existing policy schemes as a specialized topic.

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## ANNEXES

### Annex 1- Reference models for assessment of food waste valorization priority

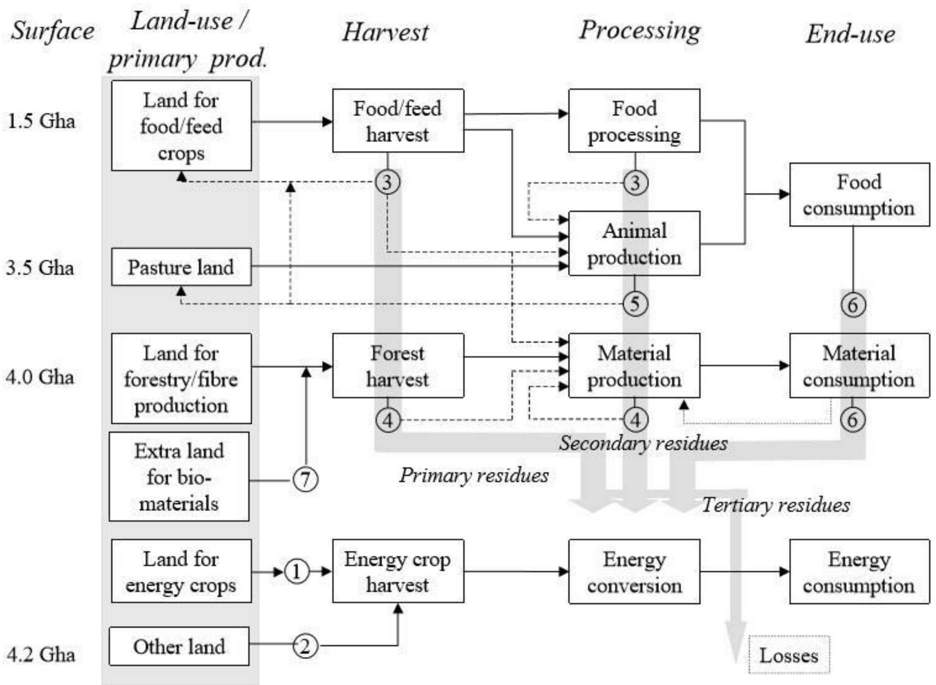


Fig. 1. Overview of various types of biomass flows and the global land surface (Based on: [1,22]). The black arrows indicate the main product flows, whereas the dotted lines show potential non-energy applications of various residue categories. The gray arrows represent the potential energetic use of the resources (1 = energy crops, 2 = energy crops at degraded land, 3 = agricultural residues, 4 = forest residues, 5 = animal manure, 6 = organic waste, 7 = bio-material).

Figure 1- Biomass flow and use of secondary resources for biomass/biofuel production (Hoogwijk et. al., 2003)

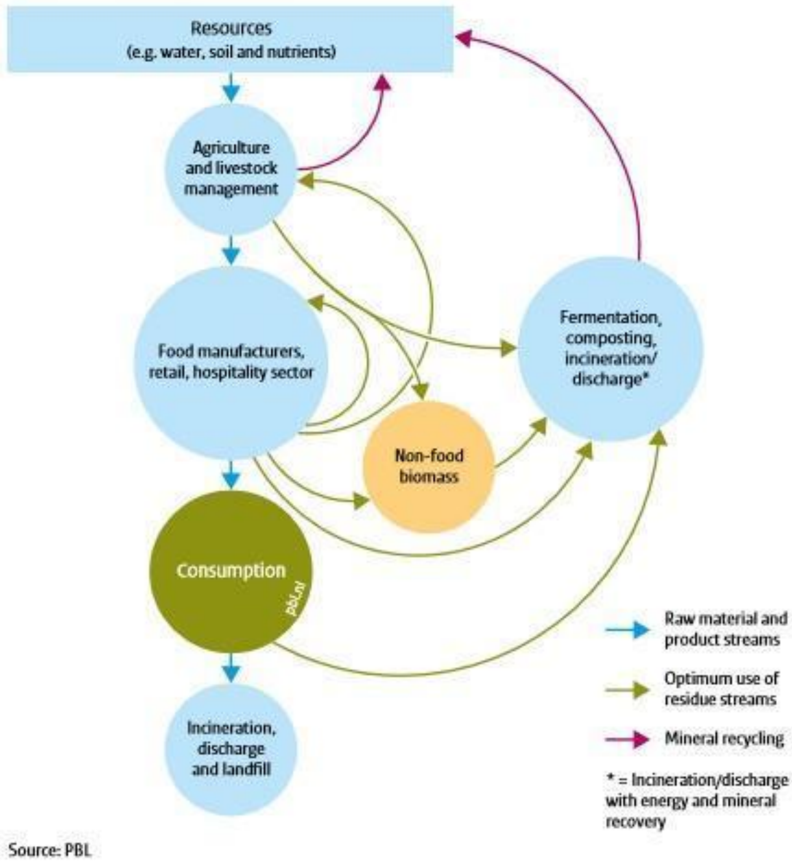


Figure 2- Circular model of food supply chain in the Netherlands (Rood et. Al., 2017).

## Annex 2- Food waste amount in Dutch households in 2016 divided by type of food and disposal route

Waste per solid food product group (including sauces, fats and dairy products)

| | Composition analysis (solid) | | | | Self-assessment | | Other routes | Total | |
|---|---|---|---|---|---|---|---|---|---|
| **Product groups** | **Residual waste** | **VFG waste** | **Total (kg/ year)** | **Percen-tage** | **Residual waste + VFG waste** | **Other routes** | **Weight compo-sition analysis x % self-assessment** | **Weight (kg/year)** | **Percen-tage** |
| Meat | 2.45 | 0.19 | **2.64** | 8.7% | 92% | 8% | 0.24 | 2.88 | 7.0% |
| Fish | 0.12 | 0.03 | **0.15** | 0.5% | 89% | 11% | 0.02 | 0.18 | 0.4% |
| Cheese | 0.66 | 0.03 | **0.69** | 2.3% | 92% | 8% | 0.06 | 0.75 | 1.8% |
| Dairy products* | 2.17 | 0.03 | **2.20** | 7.2% | 32% | 68% | 4.59 | 6.81 | 16.5% |
| Eggs | 0.18 | 0.02 | **0.20** | 0.7% | 92% | 8% | 0.02 | 0.22 | 0.5% |
| Vegetables | 4.07 | 1.12 | **5.19** | 17.1% | 91% | 9% | 0.48 | 5.67 | 13.8% |
| Fruit | 3.08 | 1.33 | **4.41** | 14.5% | 91% | 9% | 0.41 | 4.82 | 11.7% |
| Potatoes | 1.59 | 0.65 | **2.24** | 7.4% | 91% | 9% | 0.21 | 2.45 | 6.0% |
| Bread | 5.59 | 0.79 | **6.38** | 21.0% | 70% | 30% | 2.77 | 9.15 | 22.2% |
| Pastry and cake** | 1.15 | 0.02 | **1.17** | 3.9% | 70% | 30% | 0.51 | 1.68 | 4.1% |
| Leftovers from meals | 0.09 | 0.08 | **0.17** | 0.6% | 92% | 8% | 0.01 | 0.18 | 0.4% |
| Rice**** | 0.68 | 0.08 | **0.76** | 2.5% | 90% | 10% | 0.09 | 0.85 | 2.1% |
| Pasta**** | 0.72 | 0.07 | **0.79** | 2.6% | 90% | 10% | 0.09 | 0.88 | 2.1% |
| Sweets and snacks | 0.68 | 0.01 | **0.69** | 2.3% | 100% | 0% | 0.00 | 0.69 | 1.7% |
| Sandwich toppings | 0.20 | 0.00 | **0.20** | 0.7% | 100% | 0% | 0.00 | 0.20 | 0.5% |
| Sauces and fats*** | 1.04 | 0.01 | **1.05** | 3.5% | 66% | 34% | 0.55 | 1.60 | 3.9% |
| Soups | 0.18 | 0.00 | **0.18** | 0.6% | 19% | 81% | 0.75 | 0.93 | 2.3% |
| Other | 1.04 | 0.20 | **1.24** | 4.1% | 100% | 0% | 0.00 | 1.24 | 3.1% |
| **Total** | **25.69** | **4.66** | **30.35** | 100% | | | **10.80** | **41.18** | **100%** |

*Table 4: Waste per product group of solid food via residual waste, VFG waste and other routes (calculated based on percentages from the self-assessment).*
** Self-assessment percentages based on 3/4 of thick dairy products and 1/4 of liquid dairy products*
*** Percentages for bread-based pastry and cake. In practice, these will probably be lower than bread.*
**** Weighted average of sauces and fats (gravy, etc.).*

**Annex 3- Gross Bio-based material consumption in the Netherlands, 2010-2015**