Food waste high value exploitation hypothesis testing

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List of abbreviations

AD	Anaerobic Digestion
EU	European Union
FA	Framework for Action
PWP	Pilot Working Platform
WP	Work Package

1 Executive Summary

1.1 Objectives of work

High value exploitation (such as production of food ingredients, enzymes and neutraceuticals) is considered a more appealing alternative to traditional valorisation (largely as animal feed) or waste treatment of rest flows from food chains and food waste.

By extracting high value food ingredients, like bioactives, flavours or fibres, high added value can be generated from food residues/wastes. However, intensive extraction processes will induce high costs. In order to test the importance of high-end valorisation strategies, this report evaluates potential benefits and drawbacks, as well as favourable conditions for high-value food waste exploitation through a number of scenario studies. This will help business stakeholders to understand which valorisation options in specific conditions are most relevant.

Food processing wastes/sidestreams can be exploited for high-value applications like extraction of bio-molecules (bioactive compounds such as carotenoids, phenolic compounds and other anti-oxidants essential oils, beta-glucans, volatiles…), polysaccharide, lignin and protein-based fibres, etc. Such extracts serve as functional ingredient and additives in food for shelf life extension, natural colouring, increasing the nutritional value and provide health-beneficial (dietary) properties in food. (Fritsch *et al.*, 2017).

With an eye on the large volumes of food waste generated in Europe, the production potential for high-value materials is high. Still, high-value food ingredients are largely derived from dedicated crops and food wastes/by-products are still largely used in animal feed, landspread or discharged as waste.

This report shows the factors that determine when high value exploitation would be most successful. By means of a number of product examples we illustrate how situational conditions affect feasibility of such high-value exploitation options:

- input material price;
- extraction costs, specifically effect of scale (economies of scale: advantage of large-scale with respect to amongst others fixed capital and labour costs);
- market and prices for reference applications: the European feed market is a mature buyer of by-products (both liquid and dry) for animal feeds;
- logistic costs: small-scale processing may benefit from small scale size if the input material can be sourced locally in a small area; likewise short distance toward end-users can be advantageous.

1.2 Approach

The method of techno-economic analysis, as presented in REFRESH D6.5 is applied to a number of processing/valorisation chains that convert food wastes/side streams to high-value products. Analyses of cost models demonstrate the decisive importance of specific conditions on economic feasiblity of such high value valorisation options.

1.3 Results

For each of the side streams analysed a positive business case was possible, in which high-value food ingredients are produced at competitive prices from streams that are currently treated as waste or used for feed.

Based on the cases a number of critical factors for production plans was identified:

- **scale size** of the processing plant (intensive processing generally requires capital-intensive processing; economies of scale are very relevant then);
- in order to feed the large-scale plant, sufficient **supply from** a **local** or from **regional waste streams** is essential (in case collection from larger distances is needed to attain sufficient scale sizes, transportation costs may significantly raise the total costs of production, as shown in REFRESH D6.11);
- **co-production of multiple products** according to principles of biorefinery is found essential for feasible extraction of high-value products (high-value components + bulk fraction, like oil + feed from tomato seeds shown in this report and natural carotene + yellow oil in palm oil refinery, analysed in EU-RESFOOD);

Next to efficient and effective production, the value and market position of the products is essential. Most obviously the value of an existing reference product is taken. However, some proviso are appropriate:

1. When recognized as a '**natural product**' the plant-derived ingredients may have a premium price compared to synthetic variants, like for vanillin and carotenoids. Market demand for natural food ingredients is rapidly growing.
2. Although market demands for natural food ingredients are growing, product **prices may vary**, and especially when producing volumes that are large compared to the current global production they may go down. This will affect the business case.
3. **Product quality** and other attributes may play a role in product pricing. Especially a food waste derived product may significantly differ from the reference products (which are often derived from homogeneous, application-oriented materials). The quality waste material – not specifically optimised for the product – may result in suboptimal products. On the other hand, the sustainable sourcing may induce added value for certain markets.

Altogether, this report demonstrates that the broadly recognized conception that food waste (more specially food processing side streams) are adequate sources for high value food ingredients can be realized in profitable business.

2 Introduction

2.1 Background

With an eye on the large volumes of food waste generated in Europe, the production potential for high-value materials is high. It is broadly recognized that food processing side streams are very suitable sources for that (see e.g. Nagarajan et al., 2017). Furthermore, extraction technologies have increasingly high technology readiness and signifant progress is made on technologies for further optimisation of extraction/biorefinery processes. However, most by-products are still used as feed, landspreaded or treated as waste, unless relatively low-tech extraction technologies suffice for generating food ingredients (like recovery of brans from cereals and extraction of oils) (Fritsch *et al.*, 2017). Pricy food ingredients are still largely derived from dedicated crops. For instance for polyphenols "about 40% of these are herbal extract, 10% are fruit extract, and 10% are tea extract…" (Alibaba, 2019).

For improving competitiveness of waste/by-product derived extraction, the processes could be improved with regard to extraction yield or reduce labour costs. Furthermore, simplification and generalisation of the methods may increase applicability, en hence improve return-on-investments. (Fritsch *et al.*, 2017).

Decision taking will benefit from better understanding specific conditions for economic feasiblity of such high value valorisation options.

2.2 Aim of work

The aim of the work is to increase the exploitation of food & packaging waste by:

- helping business stakeholders to identify waste streams (organic and packaging) that are appropriate to valorise due to their robustness of supply, quality and composition, and for which products and outputs might be realised that are technologically feasible, economically viable, legislatively compliant and environmentally sustainable/beneficial;
- valorising post-consumer putrescible waste;
- helping policy makers to identify and implement improvements to the legislation that will reduce unnecessary restrictions on valorisation (including use in feed production, whilst maintaining appropriate safety and quality standards).

Through a number of examples we will show that no uniform answer can be given to the question whether high-value exploitation is beneficial, but show what conditions are decisive.

2.3 Approach

The first step is a mapping of the waste generated and scenarios for the potential application: (1) estimate typical composition of the waste stream, (2) identify potential (high value) food ingredients that can be generated from the wasted product, (3) sketch logistic scenario's, connected to the current generation of these waste streams, with either processing at the local scale of generation of the waste stream at one location or at a centralized location.

The second step is techno-economic analysis for the scenario's through the method of techno-economic analysis as presented in REFRESH D6.5. A techno-economic analysis combines designing a processing chain including all unit operations with estimating capital and operational expenses. Next, end product cost estimates can be derived from the resulting economic model. Through scaling factors the effect of scale size on product cost price is also shown.

In this report cost-benefit analyses of converting tomato processing by-products to valueable food ingredients are presented. These results are combined with conclusions on extracting dietary fibres from chicory pulp (presented in REFRESH D6.5). The analysis demonstrates the decisive importance of specific conditions on economic feasiblity of such high value valorisation options.

3 High value exploitation: extracting valuable compounds

As explained in the previous section, most side streams from food chains are used as feed, landspreaded or treated as waste, whereas pricy food ingredients are mostly derived from dedicated crops. Nevertheless some high value food ingredients are derived from side streams. A typical example is production of pectins and limonene from citrus fibre:

> Worldwide annually 20 Mton of citrus fibres are produced as a side stream of the production of juice (Attard, Watterson et al. 2014). The largest part of these peels is used as cattle feed. Part of the stream (~12%) is used for the production of pectin. The pectin is used as a gelling agent in food products such as jams or as a stabiliser or thickening agent.
>
> The most important companies in terms of volume of pectin production are: CP Kelco, Danisco, Cargill, Yantai en H&F. The total volume 45.000 – 50.000 ton and 850 M US$ in 2013. The annual market growth is 5-6% (Bomgardner 2013). CP Kelco has increased its capacity between 2011 en 2015 with 50% in Denmark and Brasil. The current market value of pectin is 17.500 US$/ton which is increasing (IMR-International).
>
> The production process for pectin from citrus peels starts with imported dried citrus peels that are solubilized in acid, which liberates 1/3 of the pectin approximately. The material is filtered to separate the solubilized pectin from the residual plant material. Subsequent evaporation increases the pectin concentration from 1% to 2-3%. Adding alcohol precipitates high-molecular weight pectin, which is separated by centrifugation and subsequently dried. All the alcohol used in the process is generally recovered.
>
> Besides pectin, limonene is produced from citrus peels. Limonene is used in cosmetics and cleaning agents, but also as a green solvent. The current market volume of limonene is 70.000 ton per year and growing fast, leading to shortage of the market (Fidalgo, Ciriminna et al. 2016). Limonene is produed from orange peels via mechanical treatment followed by steam distillation. The fruits are pressed, releasing juice and limonene that floats on top of the juice fraction. A second pressing step of the pulp releases more limonene. The peels are mixed with water and distilled at 97°C. After condensation a 90 – 95% pure limonene fraction can be recovered that floats of top of the condensed water (Ciriminna, Lomeli-Rodriguez et al. 2014). The value of limonene varies between 3.500 – 11.000 US$/ton (FBC Chemical).

This side stream valorisation practice is possible through the very favourable conditions:

- the citrus fibre is available at large volumes in the factories, during long production seasons (thus the extraction factory profits from economies of scale, with minimum transportation costs);
- the price for alternative outlet is low (thus the material costs are minimal);

- the food ingredients are shelf stable (the pectin and limonene can be traded globally).

Most sidestreams, however, are generated at lower volumes, which makes them less suitable for the capital-intensive processing. Possibly less capital intensive processing, such as mild processing, will lower economic feasible scale sizes. Increasing demand for ‘natural ingredients’ may facilitate this development.

During the last decades, substantial efforts in research have been made in the field of novel “green” extraction methods with the purpose of mining natural products from side streams of the food processing industry. This is reflected by the relatively high number of scientific publications on alternative extraction methods (traditional reference: solvent extraction) (Figure 1). An explanation for this can be that the state-of-the-art in industry is solvent extraction based, with the following associated disadvantages. Most of the solvents used in extraction are toxic, flammable and volatile. These properties have led to the search for either less harmful solvents or the use of external fields (microwave, ultrasonic) to speed up the extraction process, increase yield and/or use alternatives to the chemical solvents.

Extraction at supercritical conditions (high pressure and temperature) can be interesting in a number of cases, but it is generally found to be cost intensive for industrial implementation. The uses of ionic fluids has important advantages and disadvantages. The most important aspect is the fact that this solvent does not evaporate. This helps the extraction in which no solvent is lost, however the product needs to be recovered from the solvent after extraction. This is generally done with evaporation which is not an option for ionic fluids. The scientific community has not yet found a good practical solution to this issue at the moment.

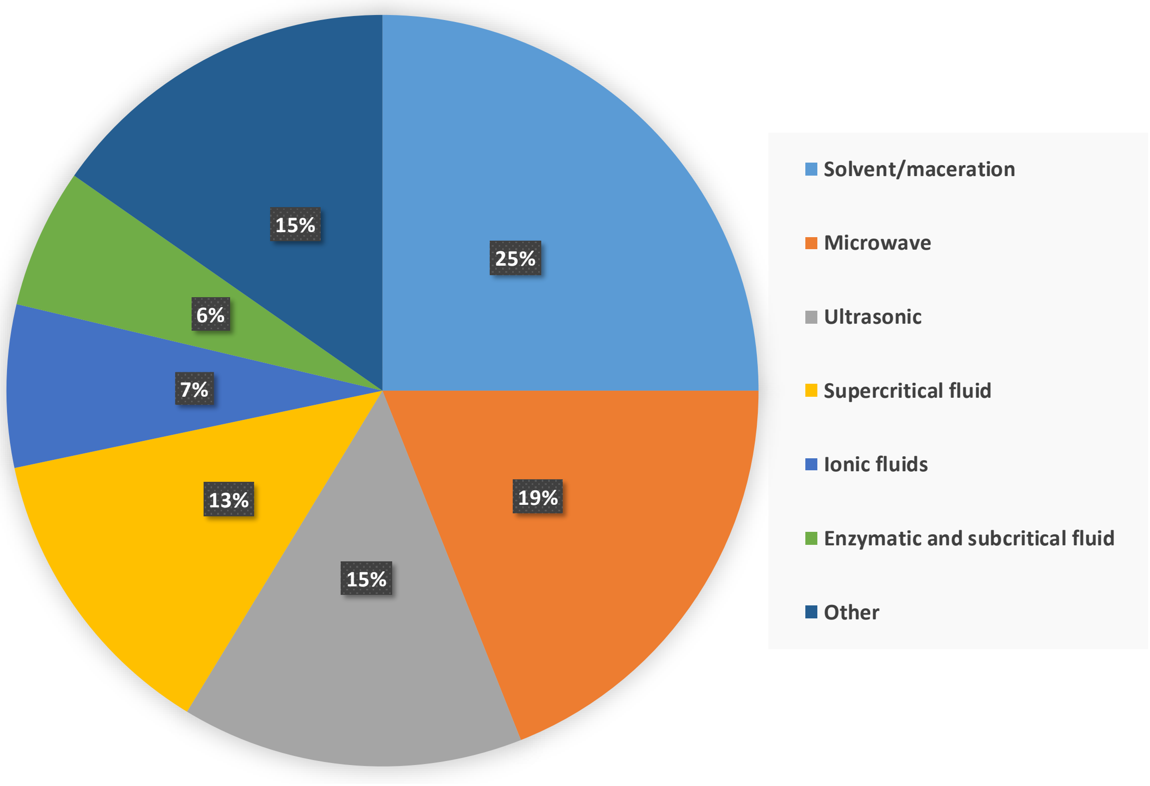

Figure 1: Most described extraction methods in literature for the mining of natural products from side streams of the food processing industry (Zuin and Ramin 2018)

Techno-economic analysis, as presented in the following chapters of this report, will help understanding when new processes are feasible.

The EU 7th framework project RESFOOD project analysed techno-economic feasibility of high-value components (carotenoids, polyphenols, sesquiterpene lactones,...) from endive waste, carrot dejuiced pulp and apple pomace. For the configurations considered it was concluded that sole production of these compounds was not competitive. Therefore, the bulk of the food-processing by-product should first be valorised towards a major compound (protein, fat, carbohydrate or fibre). During the refining of the first crude extract to a more pure extract, minor compounds are often separated from the crude extract. At this point during processing, the possible valorisation of the minor compound should be kept in mind. For example, the main source for the production of natural carotene is palm oil. However, palm fruits are not produced for carotene, but for their oil. By refining the red palm oil into a yellow oil, i.e. separation of carotenes from the oil, the carotene as minor compound can be valorised as a high-added value chemical.

In the following chapters we show more detailed economic analysis results in order to increase the understanding of critical conditions for feasibible high-value valorisation.

4 Methodology of techno-economic evaluation

Economic feasibility of food waste and side stream valorisation options is assessed through the techno-economic analysis method as presented in REFRESH D6.5. This method (Figure 2) estimates the production costs based on the process flow diagram for the intended process, using generic process cost parameters (supplemented with case-specific parameters), based on proven practical cost figures from scientific literature and knowledge of experts and industry.

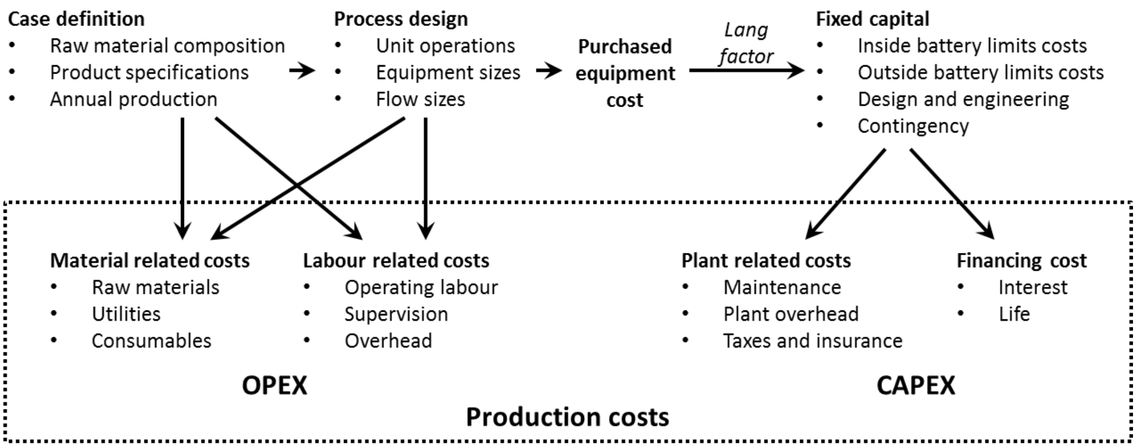

Figure 2. General approach to estimate production costs.

The methodology consists of the following steps:

- Case definition: specification of raw material, including its production profile (annual volumes, seasonality, etc.) and logistic setting (affecting amongst others collection and/or distribution costs).
- Process design, based on either existing processing chains or from pilot or lab-scale processing experience. When designing it from a lab or pilot scale process, a process engineer may redesign parts of the process that are more logical in a full-scale process.
- Deriving cost and income estimates for the intended process equipment, based on dedicated cost data from:
    - Maroulis (2008) – Food Plant Economics
    - Sinnott (2009) – Chemical Engineering Design
    - Towler (2013) – Chemical Engineering Design
    - SuperPro Designer – equipment cost database
    - recent quotations and/or expert knowledge

The cost figures in these data sets are given for a specific equipment dimension; they are corrected to the process design dimension through scaling models. Optionally the equipment costs may be corrected for historic price development (see REFRESH D6.5).

The sum of the equipment cost is defined Purchased equipment costs (PEC) or Inside battery limit costs (ISBL costs), see Figure 3.

- Estimating the total capital investment costs (direct capital costs related to investments, amongst which the building, piping, etc., and indirect capital costs, like engineering costs, permits, project management, etc.). The total capital costs are estimated by multiplying the equipment costs by a multiplier (the Lang factor). Mostly this is estimated by the expert between 3 and 6, depending on the type of project; typically 5.2 for new (green field) plants and on 4.0 for plant extensions.
- Variable costs consist of raw material costs, labour costs (derived from the estimated number of shift positions), energy and other utility costs, waste treatment costs and other operational costs. Annual plant related costs and financing costs are typically estimated at 10% of the fixed capital per year each.
- Estimates for income are based on estimated product yields, price estimates for the product generated and prevented costs. Specifically for options of food waste valorisation, prevention of food waste management may result in substantial cost saving.

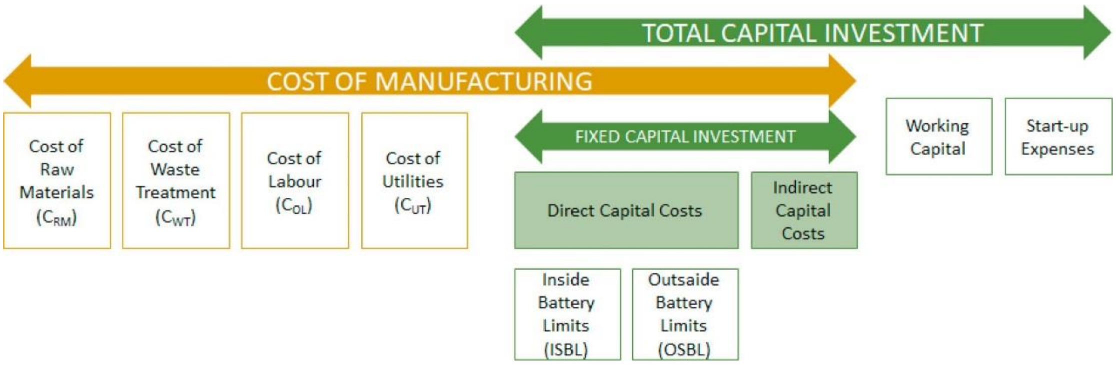

Figure 3. Total capital investment and cost of manufacturing calculation framework (Cristóbal *et al*., 2018).

The capital investment costs, variable costs and annual income can be combined in a cost-benefit sheet to estimate economic feasibility of the food waste and sidestream valorisation options. The method will be applied for tomate side streams in chapter 6 of this report.

5 Scenarios for tomato side stream valorisation

Tomatoes are amongst the most popular vegetables in the world. The global production doubled from 90 million tonnes in 1997 to 180 million tonnes in 2016. (FAO 2016). The 10 countries with the largest tomato production are displayed in Figure 4.

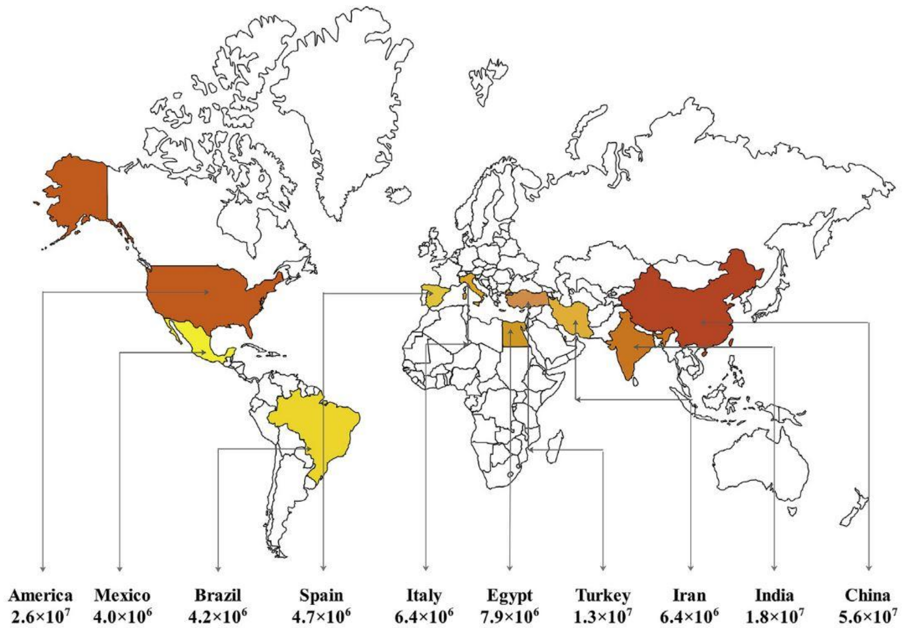

Figure 4: Tomato production in top 10 tomato producing countries in 2016 (Lu, Wang et al. 2019).

Tomatoes are consumed as fresh vegetable and as a processed product such as paste, juice, ketchup or puree. Significant side streams are generated from both the fresh chains as well as from the processed chains (surplus/reject/spoilt tomatoes and pomace rich in peels and seeds respectively). European tomato production results in a total waste stream of 20.5% (Figure 5). 8% loss occurs at the consumption phase, 4% in post-harvest chain (4%) and 8.5% in industrial processing.

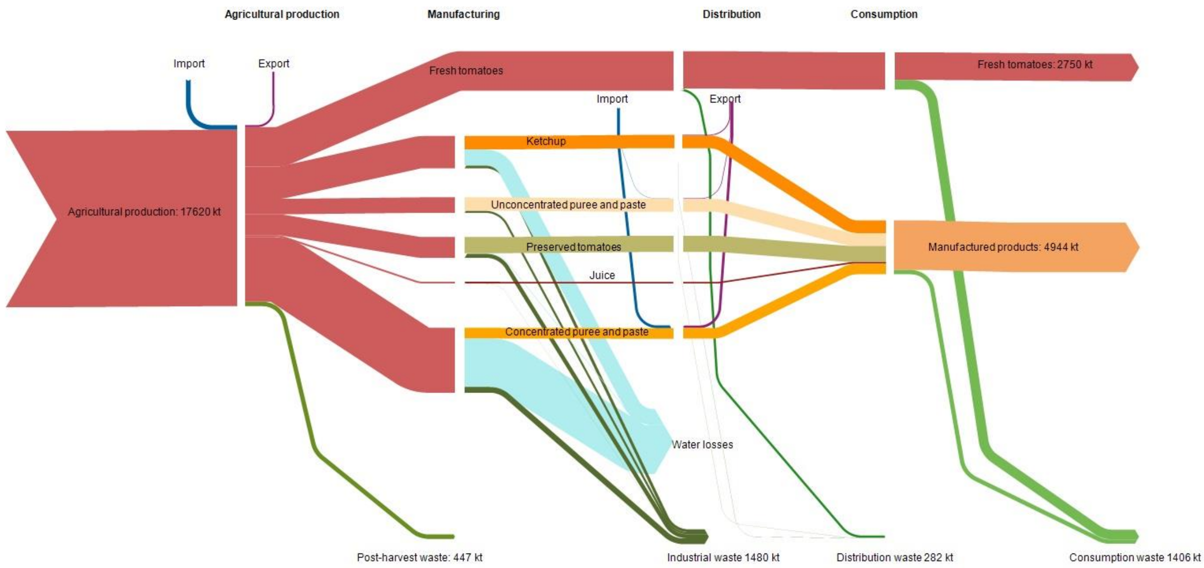

Figure 5: Tomato wastes in Europe (2015) (Cristobal, Caldeira et al. 2018)

Because the side streams have different compositions and are generated in different geographic settings, their valorisation is also different. In this report valorisation options of two side streams are evaluated:

- waste from fresh chains (mainly spoiled and reject tomatoes);
- industrial waste (pomace).

An overview of the composition of these side streams is given in Table 1.

Table 1: Overall composition of the main residue streams (Strati and Oreopoulou 2014), (Stajcic, Cetkovic et al. 2015)

	Spoiled tomatoes	Peels	Seeds
Dry weight	93.5		
Protein (% dw)	1.2	10	32
Fibre (% dw)	50		
Ash (% dw)	0.5	4.5	4.5
Fat (% dw)	0.2	5	22
Carotenoids (µg/g dw)		793.2	157.9
-Lycopene (µg/g dw)		413.7	130
-B-carotene (µg/g dw)		149.8	28

The composition of different side streams can also be found in FoodWasteEXplorer, a tool developed as part of the REFRESH project (www.foodwasteexplorer.eu).

Below we define scenarios for valorisation both categories of waste streams; techno-economic feasibility of these options will be analysed in following chapters.

5.1 Option for valorisation of wasted fresh tomatoes

Option: tomato paste production from wasted fresh tomatoes

In fresh supply chains and supply to processing processing industries, tomatoes are rejected for various reasons. Mostly, these tomatoes do not re-enter the food chain and the highest valorisation of this material is a feed application.

However, if the tomatoes are rejected for being off spec in terms of shape, size, colour or other harmless reasons, the material could still be used in food products. Currently, rejected tomatoes are commonly available at rural production areas and are mostly treated as waste or used as feed (REFRESH D5.6). Processing these tomatoes into a paste to be used in food application seems a reasonable valorization option.

Techno-economic feasibility for the following settings, for tomatoes of different sources and at different scales:

- Spoiled tomatoes from a single greenhouse (150 ha, estimated at 3,000 tonnes/y) are available almost year-round and are processed at site with 8 production hours a day. The tomatoes have no costs and there are no transport costs.
- Spoiled tomatoes from 10 greenhouses (150 ha each) are available yearround and are processed centralized with 16 production hours a day. The tomatoes have no costs, average transportation distance is 20 km with transportation costs of € 0.16 /(ton·km).

These waste-based scenarios will be compared to a standard situation, where dedicated crops are produced for canning:

- Standard (centralized) prossessing at large scale: 2000 production h/y (in 3 months, 24 hours a day), average transportation distance is 100 km with transportation costs of € 0.16 /(ton·km) The raw material costs are € 75 /ton tomato.

5.2 Option for valorisation of tomato processing side streams

Options: producing oil for tomato seeds and caroteinoids from tomato peels

In processing, tomato pomace is generated. This pomace consists of mainly seeds and peels. In landfilling it is quite polluting because of the significantly high nutrient content; because of the high moisture and nutrient content combined with low fibre content it is not very suitable for composting. A significant fraction is used as feed, but drying is necessary because it rapidly spoils.

A number of valorization routes of tomato pomace via bio-refinery are investigated. Further processing and utilizing tomato pomace helps on one hand to reduce the environmental footprint of the tomato production and processing industry and on the other hand to create additional usable products and value, such as lycopene, carotenoids, dietary fibres, pectin, tomato seed oil and proteins.

The other significant side stream in the production of ketchup and concentrated puree and paste, water losses in Figure 5, is removed by evaporation. This results in a loss of tonnage. The concentration step preserves the ingredients of the tomato in the product and generally takes place in the country of production in order to increase shelf life and and reduce transport costs. The removed water is not a valueable side stream.

During the production season, generally two to three months per year, the tomato processing lines are operated continuously at maximum capacity. Side streams become available only in this period.

The typical capacity of a tomato processing plant with the associated products is shown in Table 2.

Table 2: Tomato processing streams (ton) in the Conesa factory (https://www.conesagroup.com)

	Tomatoes in	concentrate out	diced out	powder out
Day	6.500	1.912	459	134
Month	198.250	58.309	13.994	4.082
Campaign	340.000	100.000	24.000	7.000

The specific composition of the side stream (pomace) is based on the product and the associated process. For example, the pomace produced from canned or diced tomatoes mainly consists of tomato peels, without seeds. Production of some other homogenized tomato products, such as juice or paste, result in a side stream that consists mainly of peels and seeds. On a dry basis the seeds account, on average, for 35% of the total amount of the pomace, but can account for up to 45% of the resulting tomato pomace, depending on the factory layout and product mix (Kaur, Sogi et al. 2005). Figures from this publication have been combined with Table 2 to estimate the total amount of side streams of this specific factory (Table 3).

Table 3: Estimate of tomato processing side streams from the Conesa factory (Figure 1)

Estimated side streams (ton per day)	Min	Max	Average
Seeds dw	18	30	24
Peels dw	33	55	44
Total dw	51	85	68
Total wet	195	325	260

Based on the estimated side streams (Table 3) the amount of the main constituents (protein, fat, ash and carotenoids) that are present can be seen in Table 4. Obviously the seed fraction has a relatively high content of protein and oil, while the carotenoids, such as lycopene are mainly be found in the peels fraction. A total amount of 35 kg carotenoids per day may seem a low value, but with an estimated price of €1000 per kg carotenoids, significant value can be generated. This means that the added value when all the carotenoids from the peels would be valorised would add up to €35.000 per day.

Table 4: Side stream composition and absolute amounts of the most important constituents

Composition side streams	Seeds (% dw)	Peels (% dw)	Seeds total (ton dw/day)	Peels total (ton/day)
Protein	32	10	7,7	4,4
Fat	22	5	5,3	2,2
Ash	4.5	4.5	1,1	2,0
Carotenoids	$1{,}6*10^{-2}$	$8{,}0*10^{-2}$	$3.8*10^{-3}$	$3.5*10^{-2}$

Through separating the seeds and peels they can both be valorised for different high-value applications. For example, the seeds of the tomatoes can serve as a novel oil-rich side stream with a protein-rich press cake and the peels could serve as a base for carotenoids extraction such as lycopene. The remaining pulp could be used for the production of pectin or dietary fibre or serve as cattle feed.

5.2.1 Tomato seed oil extraction

Tomato seed oil have been used for the production of tomato seed oil in the early 20^{th} century. Tomato seed oil can be produced from tomato seeds by pressing with expellers or by solvent extraction. Generally extraction gives the highest yield in oil recovery and is widely used in the production of vegetable oil. Most common solvent applied is hexane. It is likely that hexane will be used for the extraction of tomato seed oil as well, if an industrial process would be set-up.

Tomato seed oil appreciated for the very high level of unsaturated fatty acids, which account for ¾ of the oil. Mainly linoleic acid with some oleic acid accounts for the unsaturated fatty acids. The value of tomato seed oil should be compared with vegetable oil from other sources such as for example safflower oil, which is also rich in linoleic acid. The value of safflower oil is estimated to be €10 (sales price per kg via google €11,50). The cost price of safflower oil is estimated at 30% of this value, so €3/kg. Safflower seeds contain approximately 37% oil (Applewhite 1966), which is higher than the oil content of tomato seed, which is 22%. The tomato seeds are currently a side stream however and can be obtained at very limited costs. Therefore a lower amount of oil in the seeds does not necessary lead to a poor potential economic viability.

The tomato seeds being a waste stream at this moment, results in a lack of attention for the quality of the seeds and the associated oil. This results in a lot of literature finding high levels of oxidation of the oil. This is an effect of the processing and as soon as the tomato seed oil becomes a product that adds value, the production process in which tomato seeds are separated will change to improve the oil quality. The side stream of the tomato seed oil production is a tomato seed press cake after desolvatising. This means that the tomato seed residue has been pressed and heated to remove all residual hexane after extraction. Legislation is very strict on hexane residues after solvent extraction of vegetable oil.

Tomato seed press cake is rich in protein. Proteins account for 25 – 40% of the seed dry matter. The removal of the oil from the seeds will further increase the protein content. The amino acid score of the protein is limited by low amounts of tryptophan and methionine (Tchorbanov 1986; Turakhozhaev 1979; Brodowski and Geisman 1980; Latlief and Knorr 1983; Mechmeche, Kachouri et al. 2016; Kramer and Kwee 1977; Seikova, Simeonov et al. 2004). The protein in tomato seeds consists mainly of storage protein, which has a limited solubility. Extraction of the protein can be realised by treatment with NaOH, salts, Na_2SO_3 or combinations thereof. The result is a partly hydrolysed soluble protein. Several articles give detailed information about the functional properties of the extracted protein and the potential applications that are associated with these properties. General rule of thumb for food protein products is a selling price of €1.500/ton for protein concentrate with only water binding capacity and no further added value (ref. pea protein concentrate, personal communication). Specific functional properties such as emulsifying, gelling and foaming increase this value. These functional properties are generally found in soluble proteins. Tomato seed protein does not appear to have a significant functionality in food products. Also because of the limited amino acid score it has limited value as food protein, and is more likely traded as feed product. This would lead to a value of approximately €250/ton (reference: rapeseed meal, www.agrimatie.nl). Some anti-nutritional factors are present in the tomato seed protein product, such as trypsin inhibitors and phytate, which may need to be destroyed or removed by further processing of the protein in some applications (Sarkar and Kaul 2014).

The added value of tomato seed refining into oil and protein depends on the yield figures of the oil production process. When a comparison is made with a conventional vegetable oil production process, based on solvent extraction with hexane, an oil yield of 90 – 100% is reached. Assuming an oil yield of 90% in the case of tomato seed oil, a production of 200 kg oil per ton of tomato seeds with a value of €600/ton tomato seed. The remaining 800 kg of protein rich press cake has a value of €200. The net value of tomato seed after processing in total adds up to €800/ton.

5.2.2 Caroteinoid extraction from tomato peel

Tomatoes contain several carotenoids, of which lycopene is the most prevalent one (71 – 85%) of the total carotenoids, followed by β-carotene (12 – 26%) and lutein (3 – 12%) (Strati and Oreopoulou 2016). The part of the tomato that has the highest concentration of carotenoids is the tomato peel. The carotenoids being a product with a high price and the tomato peels being a waste product this combination is appealing and therefore has received significant attention in scientific literature. A substantial amount of literature focusses on the isolation of lycopene with novel extraction techniques, such as mentioned in Figure 1 (with the exception of ionic liquids) (Strati and Oreopoulou 2014). Supercritical CO_2 is a technique that may be suitable for this extraction step. Several conditions and co-solvents are described in literature. The best results are reported by (Sabio, Lozano et al. 2003) with very fine milled tomato industrial waste (345 μm) and 5% ethanol as a co-solvent at 80°Cand 300 bar. The yield at these conditions are 88% lycopene and 80% β-carotene. During extraction with supercritical CO_2 there is a risk of isomerisation of part of the carotenoids.

Various solvents are mentioned with associated extraction procedures. When selecting a solvent for carotenoid extraction, it is important to keep in mind that carotenoids are sensitive to oxidation and solvents should therefore not contain peroxides or other oxidising components. This means that, for example, tetrahydrofuran or diethyl ether should be avoided as these solvents may contain peroxide.

Ethyl lactate shows good results as an eco-friendly solvent in the extraction of carotenoids from tomato peels (Strati and Oreopoulou 2011). Extraction yield in laboratory extraction (3 times 10 fold solvent on dry tomato peel residue) shows a yield that is 5 times higher than conventional solvent mixtures for carotenoid extraction (hexane-ethyl acetate 50:50). Isomerisation of the carotenoids if however also increased when ethyl lactate is used as an extractant (Strati and Oreopoulou 2016). Ethyl lactate is an ester of ethanol and lactic acid and in the presence of water can split into those two components. This aspect is not favourable. Furthermore the boiling point of ethyl lactate is above 150°C and that will make solvent recovery more costly as compared to lower boiling extractants such as ethyl acetate and hexane. Overall an assessment should be made that takes into account both the benefits of a solvent and the associated costs (purchase, depreciation, recovery) of the solvent to make a fair judgement on the optimal solvent. Based on the current literature it in difficult to make such an assessment, therefore the solvent of choice in the process design is a 50:50 mixture of hexane:ethyl acetate, which is the current industrial state-of-the-art for carotenoid extraction.

Prices of caroteinoids: “synthetic carotenoids sell for between $250 and $2,000/kg, whereas natural carotenoids sell for between $350 and $7,500/kg. These wide price ranges are the result of the fact that several carotenoids have become commodities (such as lutein and beta-carotene), while others (such as lycopene and analogous compounds) have maintained their very high added value. DEINOVE obviously focuses on natural carotenoids.”

“Sales price: €300-€3,000/kg, Production price: €200-€600/kg”

http://www.deinove.com/en/profile/strategy-and-markets/carotenoids-market

6 Techno-economic analysis of the tomato waste valorision options

In this chapter the valorization options discussed in Paragraph 5.1 and Paragraph 5.2 are evaluated, using the method of techno-economic analysis, as presented in REFRESH D6.5, and process-specific parameters explained below.

6.1 Valorisation of spoiled tomatoes

6.1.1 Tomato paste production

The tomato paste processing costs, with different raw materials and different scale sizes (Paragraph 5.1) are estimated based on the flowsheet and assumptions from Angeles-Martinez et al. (2018). In the process the tomatoes (6% DW) are processed into a paste (32% DW), canned, and boxed.

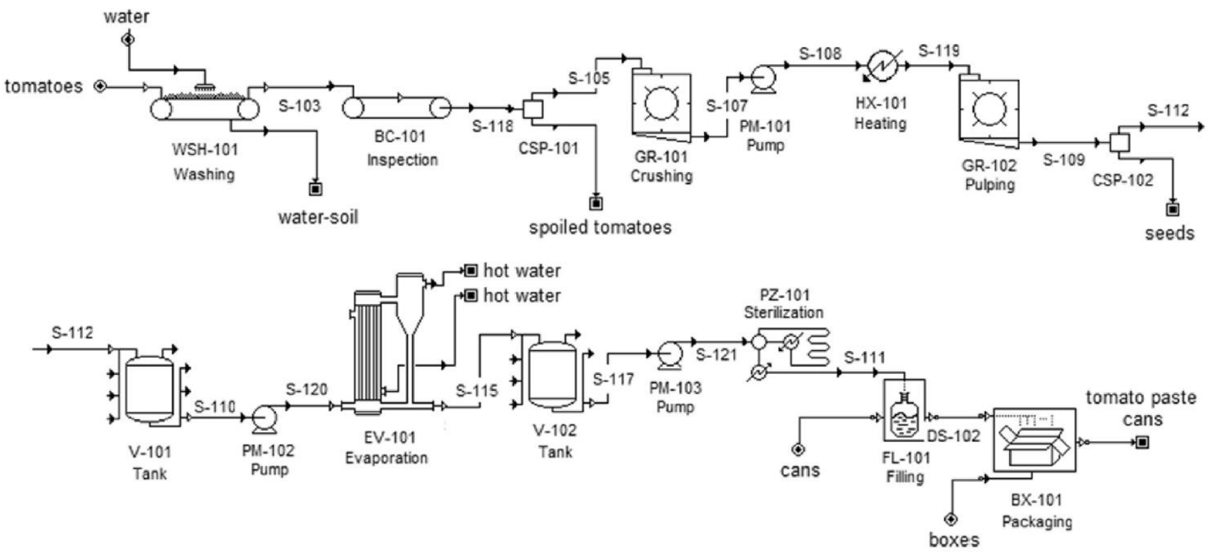

Figure 6 Tomato paste production flow sheet from Angeles-Martinez et al. (2018)

6.1.2 Assumptions on processing parameters

The production costs are based on Angeles-Martinez et al. (2018) and APV (2008) for the evaporator. The product is packed 0,41 kg paste/can, 24 cans/box, with a can price of € 0,10 /can and a box price of € 0,60 /box. The purchased equipment costs are scaled to the concenrning capacity (Table 5). The purchased equipment costs and as a result the fixed capital costs are dominated by the 5 stage evaporator.

Table 5: Plant capacity and cost parameters

	Side stream processing		Standard processing
	Small scale	Medium scale	Large scale
Plant capacity (kton tomato/y)	3.0	30	300
Production (kton paste/y)	0.56	5.6	56
Processing (h/d)	8	16	24
Operating hours (h/y)	2667	5333	2000
Shift positions (#)	0.33	2	0.75
Transport distance (km)		20	100
Purchased equipment costs (M€)	0.4	1.0	7
Fixed capital (M€)	2.1	5.1	35

6.1.3 Economic evaluation

The costs associated with production of tomato paste for the different scenarios (paragraph 12) are shown in Figure 7[1]. The operating hours differ substantially at different scales. This is related to the volumes of raw material and the expected processing hours of the company involved. Apparently, the labour related costs, plant related costs, and financing costs are largely scale-dependent.

[1] The validity of these calculations is confirmed by comparing the costs price for the Standard Processing scenario with actual cost price estimates in the market (as on http://morningstarco.com/index.cgi?Page=Current%20Market%20Price; cost prices for the cans are different, most likely due to the different can sizes).

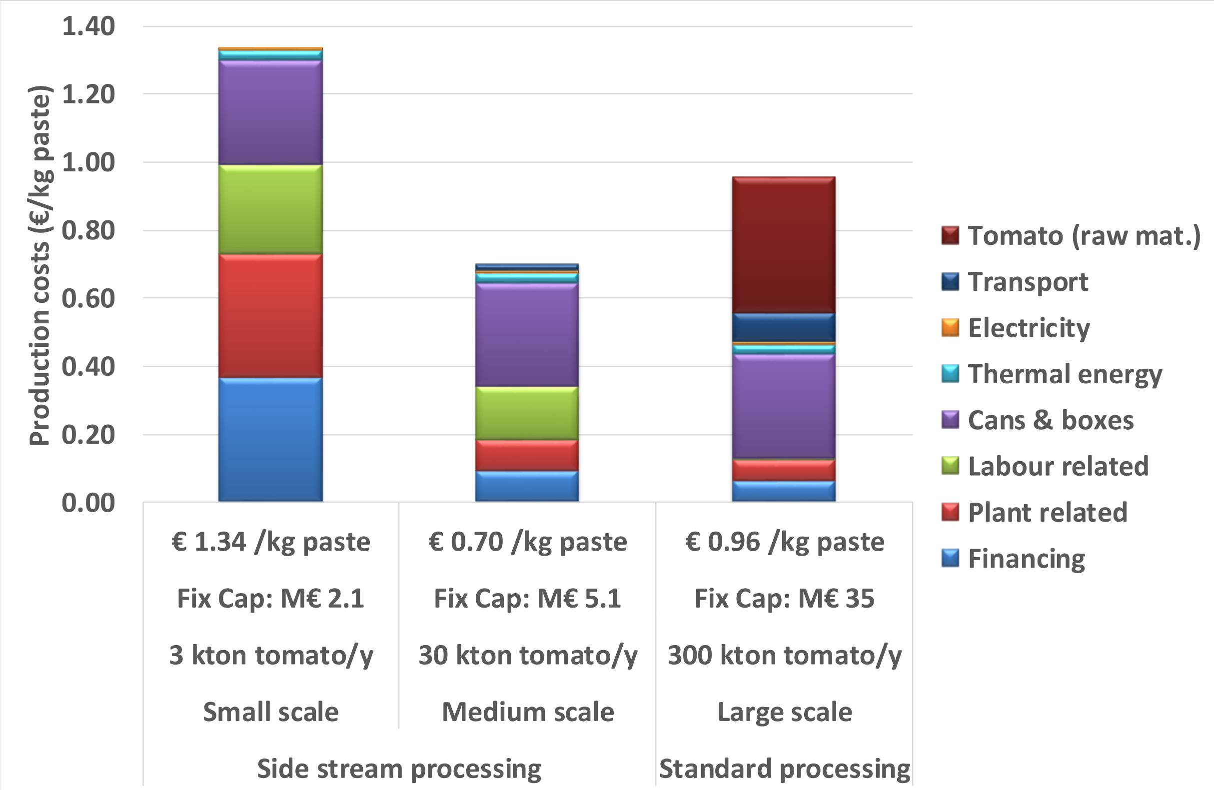

Figure 7: Calculated product costs of tomato paste, produced from tomato side stream from the primary process, at small, medium and large scale (= benchmark)

The effect of the economy of scale (continues operation, large multistage evaporator) is clear. The costs of the raw material however make the side stream processing at medium scale more cost effective in this evaluation than the larger scale processor that buys dedicated tomatos. If the tomatoes from 10 different tomato greenhouses no more than 20 km appart can be collected free of charge, the produced tomato paste from such a side stream may in fact be a feasible option. Risk-wise the full investment would be to a large extent depend on the availability of tomatoes that are free of charge. A cooperative action from the local greenhouses in setting up such a plant may therefore be more likely than a third party.

6.2 Valorisation of tomato processing side streams

In this section the costs of the production of tomato seed oil and tomato peel carotenoids are estimated for the configuration defined in section 5.2, for 2 scenarios: (1) "small scale": drying and processing the volume of pomace produced by the tomato processing factory; (2) "large scale": collecting dried pomace from 10 factories and process that a centralized plant.

It is important to take into account that the drying and sieving costs, combined with the extraction at small or large scale adds up to the total cost price. If oil extraction and carotenoid extraction were to be combined, which makes sense, the drying and sieving costs would only be required once and these costs could be divided over the two products. This is a clear example of the added value of a biorefinery approach towards side stream valorisation and is evaluated in Paragraph 6.2.7.

6.2.1 Drying and Sieving

The first step in the process is the drying of the tomato pomace and subsequently the separation of the seeds and peels (Figure 8). The composition of the different streams from the flowsheet in Figure 8 are displayed in Table 6. The pomace is dried by hot air and sieved afterwards to separate seeds and peels. This process takes place on small scale (single processing plant) to avoid transport of water and deterioration of the material. The final products are seeds which have a dry matter content of 10%.

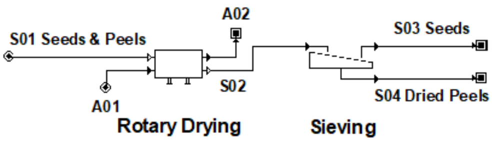

Figure 8: Drying of tomato pulp and separation of seeds and peels

Table 6: Specifications of the streams in Figure 8

		S01	S02	S03	S04
DW	% wb	26%	90%	90%	90%
Total	ton/h	10,8	3,2	1,1	2,0

6.2.2 Oil Extraction

Tomato seeds can be used to produce a vegetable oil. The oil production process is a standard hexane-based solvent extraction lay out that is displayed in Figure 9. The product is a crude tomato seed oil that can be further refined when required and a protein rich residue stream that can be applied as feed. The dry weight and size of the streams in Figure 9 are shown in Table 7. The process could be performed either on a small scale (single processing plant) or large scale (dried side streams combined from 10 processing plants).

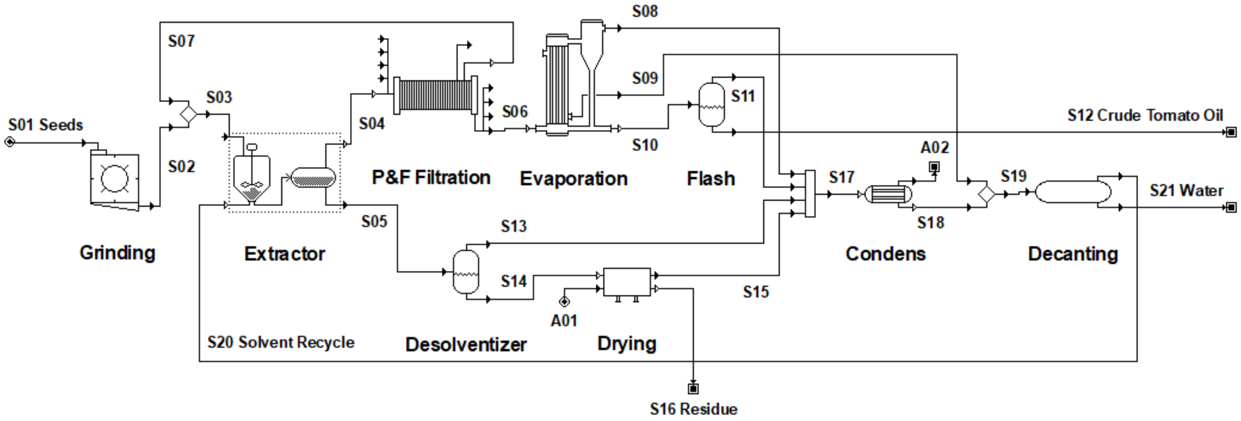

Figure 9: Tomato seed oil extraction process

The process sketched in Figure 9 starts with dry seeds that are grinded and fed to the 4-stage mixer-settler. After extraction the solid material is removed from the mixer-settler and the solids are transported to the desolventizer. The liquid fraction is first filtered to remove residual fines, which are recycled, and then fed to the evaporator to remove the solvent from the vegetable oil. The oil is flashed to remove residual solvent and leaves the process as crude oil. The solid residue passes through the desolventizer to remove the hexane and is dried before leaving the process as protein rich residue. The solvent vapours are condensed and decanted to remove water, after which the solvent can be reused in the process. The size of the streams and the dry weight content is displayed in Table 7. The process produces 0,2 t/hr crude oil, 0,8 t/hr protein rich residue and 0,1 t/hr water from 1,1 t/hr input of tomato seeds. This scale corresponds to a single processing plant (= small scale). The large scale is ten times this scale, processing the amount of side stream that occurs at ten tomato processing plants.

Table 7: Dry weight and size of the streams in Figure 9

		S01	S02	S03	S04	S05	S06	S07	S08	S09	S10	S11	S12
DW	% wb	90%	90%	90%	98%	92%	98%	93%	98%	98%	99%	92%	100%
Total	ton/h	1,1	1,1	1,1	1,1	1,2	1,0	0,0	0,3	0,5	0,2	0,0	0,2

		S13	S14	S15	S16	S17	S18	S19	S20	S21
DW	% wb	78%	99%	100%	99%	96%	87%	92%	100%	0%
Total	ton/h	0,4	0,8	1,6	0,8	2,3	0,7	1,2	1,1	0,1

6.2.3 Carotenoids Extraction

The extraction of carotenoids from the peels fraction is a solvent based process as well, displayed in Figure 10. The solvent for carotenoids extraction is a more polar solvent than the one used for the oil extraction process. The solvent is mixed with ground dried peels and extracted in a 4-stage mixer-settler. The solid material is transported to the desolventizer to remove most of the solvent and subsequently to the dryer to remove the last solvent residue. The solvent vapour is condensed and recycled. The solvent from the mixer-settler is filtered and fines are removed, after which the solvent is remove by distillation. Because of the more hydrophillic nature of the solvent in this case, a standard evaporator will not suffice in effectively removing the solvent from the water and product. The largest amount of the water can be removed by nanofiltration, after which the carotenoids can be spray dried to remove the last amount of water. The product is a dry carotenoid powder. The process produces 1,6 kg/hr of carotenoids and 1837 kg/hr of residue from 2037 kg/hr of dried peels.

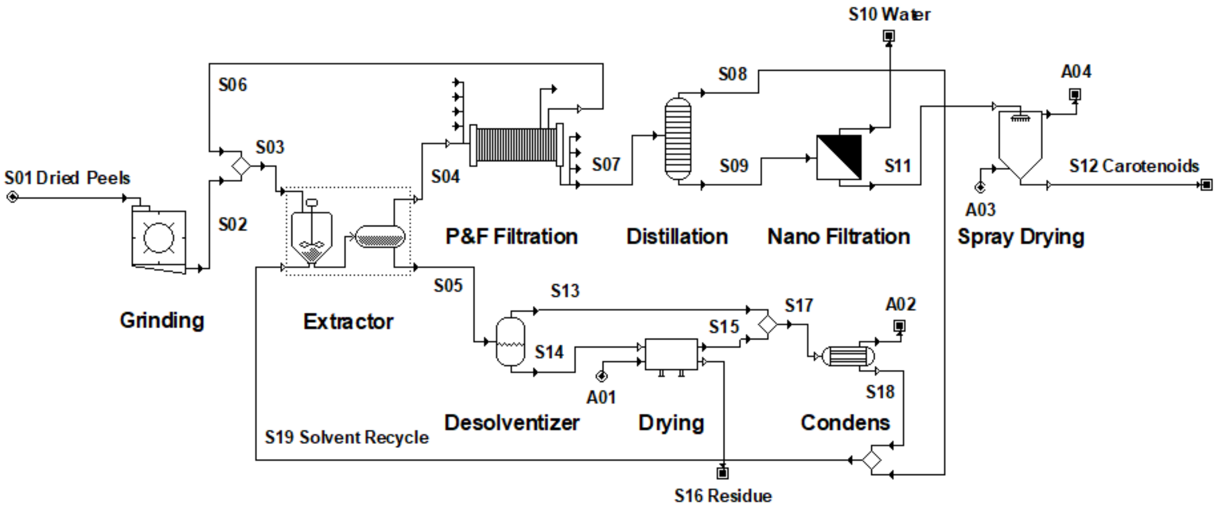

Figure 10: Carotenoid extraction process from dried tomato peels

The dry weight and the size of the streams from Figure 10 are displayed in Table 8. This size corresponds with the residue of a single factory, which is called small scale in this document. The large scale will be ten times bigger and process the side stream of ten factories. The residue that is produced in this process will consist mainly of polysaccharides from the tomato skin. The solvent is recovered from the distillation, desolventizer and dryer to be reused in the extraction process.

Table 8: Dry weight and size of the streams in Figure 10

		S01	S02	S03	S04	S05	S06	S07	S08	S09	S10	S11	S12
DW	% wb	90%	90%	90%	87%	96%	93%	87%	99%	1%	0%	20%	90%
Total	kg/h	2037	2037	2084	1688	2498	47	1640	1440	200	193	7,2	1,6

		S13	S14	S15	S16	S17	S18	S19
DW	% wb	86%	99%	98%	100%	89%	85%	95%
Total	kg/h	655	1842	264	1837	919	661	2101

6.2.4 Assumptions

The overall in- and output figures that have been used to construct the techno-economic evaluation are displayed in Table 9. These figures have been used for scaling of equipment and calculating the sizes of the different streams. The large scale case is 10 times the size of the small scale case. The yield of both extraction processes is assumed to be 99%. This is a realistic value that is widely used in multi-stage extraction processes.

Table 9: Case definition for single factory scale (small scale)

Operating hours	2000 h/yr					
Drying & Sieving		Oil Extraction		Carotenoids Extraction		
Input	26%	Input	90%	Input	90%	DW
Pulp	10.8	Seeds	1.1	Dried peels	2.0	ton/h
	21.7		2.2		4.1	kton/y
Output		Output		Output		
- Seeds	90%	- Crude Oil	100%	- Carotenoids	90%	DW
	1.1		0.2		0.0016	ton/h
	2.2		0.4		0.003	kton/y
- Dried Peels	90%	- Residue	99%	- Residue	100%	DW
	2.0		0.8		1.8	ton/h
	4.1		1.6		3.7	kton/y

The economic evaluation of the cases (small and large) was made using the assumptions stated in Table 10. The PEC (purchased equipment costs) scaling power applied is 0,6. This means that a 10 times larger factory will cost $10^{0,6}$ times as much. Drying and sieving always takes place at the production site of the side stream and is therefore always small scale (1 plant). The extraction plant is set up for 2000 working hours per year, which requires 4,8 operators per shift position. The estimated average distance for transportation of raw material is 100 km. Transport is only required in the large scale case. On small scale the extraction will take place at or close to the tomato processing site. Solvent loss was estimated at 2% of the recycle. Solvent is lost mainly with the water phase. Drying and sieving requires one shift position, extraction at small scale requires one shift position and at large scale two shift positions (both for oil and carotenoids).

Table 10: Assumptions that were used for the economic evaluation of the processes

CAPEX		
Large/Small scale	10	
PEC scaling power	0.6	
Lang Factor	4	
Plant related costs	10%	of FC/y
Financing costs	10%	of FC/y
Utility costs		
- Electricity	0.08	€/kWh
- Thermal energy	25	€/ton st.
Consumables costs		
- Hexane	0.60	€/kg
- Solvent	1.00	€/kg

Extraction		
Solvent/Input	1	
ΔH vap		
- Water	2260	kJ/kg
- Hexane	365	kJ/kg
Solvent loss	2%	of recycle
Heat dryer	2	x ΔH vap
Heat solvent recycle	2	x ΔH vap
Electricity usage		
- Drying & Sieving	20	kWh/ton in
- Extraction	50	kWh/ton in
Transport		
Transport costs	0.16	€/(ton·km)
Transport distance	100	km

Operating labour	100%	
Supervision	25%	
Direct salary overhead	63%	
General plant overhead	122%	
Labour related costs	309%	
Operators per shift position	4.8	
Operating labour costs	18	€/(oper·h)
	7.5	k€/(oper·y)
Labour related costs	111	k€/(sh pos·y)
Shift positions		
- Drying & Sieving		
- small scale	1	
- Extraction		
- small scale	1	
- large scale	2	

6.2.5 Cost estimation of tomato seed oil extraction

The calculated processing costs of the extraction of oil from tomato seeds are displayed in Figure 11. The costs of drying the wet side stream apparently contribute significantly to the total costs of the tomato seed oil. Most of these costs are based on the thermal energy requirement of the drying process (steam), which is an effect of the absence of heat integration in the drying process. Heat integration may technically be a feasible option, however in practice pulp dryers in general use hot air for drying.

The recovery of heat from water vapour that is diluted with air is generally not a feasible option. The drying of pulp with a vacuum system could be used to recover heat and therewith reduce the thermal energy requirement of the system with approximately 50%. The counterpart of this adjustment will be an increase in the electric energy requirement because of the vacuum pumps and an increase in total capital costs of approximately a factor of five due to more expensive (jacketed, vacuum-resistant tanks) equipment that is also larger because less evaporation in accomplished from a specific evaporator surface area. State-of-the-art in industry is a pulp drier based on air drying and not a vacuum system with heat recuperation. This also indicates that such a system is not feasible with the current energy and equipment prices.

The costs for the extraction plant are much smaller per kg of product. The processing on large scale results in a reduction of the costs for extraction of 50%. The transport costs that are added in the large scale case are of limited significance. If the average transporting distance from ten tomato processing plants to one central extraction facility are larger than 100 km, these transport costs will increase. Total cost price of the oil adds up to €6.6 - €8,2/kg of tomato seed oil. This is slightly higher than the price estimation (€3/kg). Valorisation of the residue (feed) and the parallel extraction of carotenoids from the peels are not taken into account in this calculation.

Total investment of a small scale plant including extraction adds up to 12 M€. Total investment for large scale processing, 10 times a drying plant and a large scale extraction plant, adds up to 93 M€.

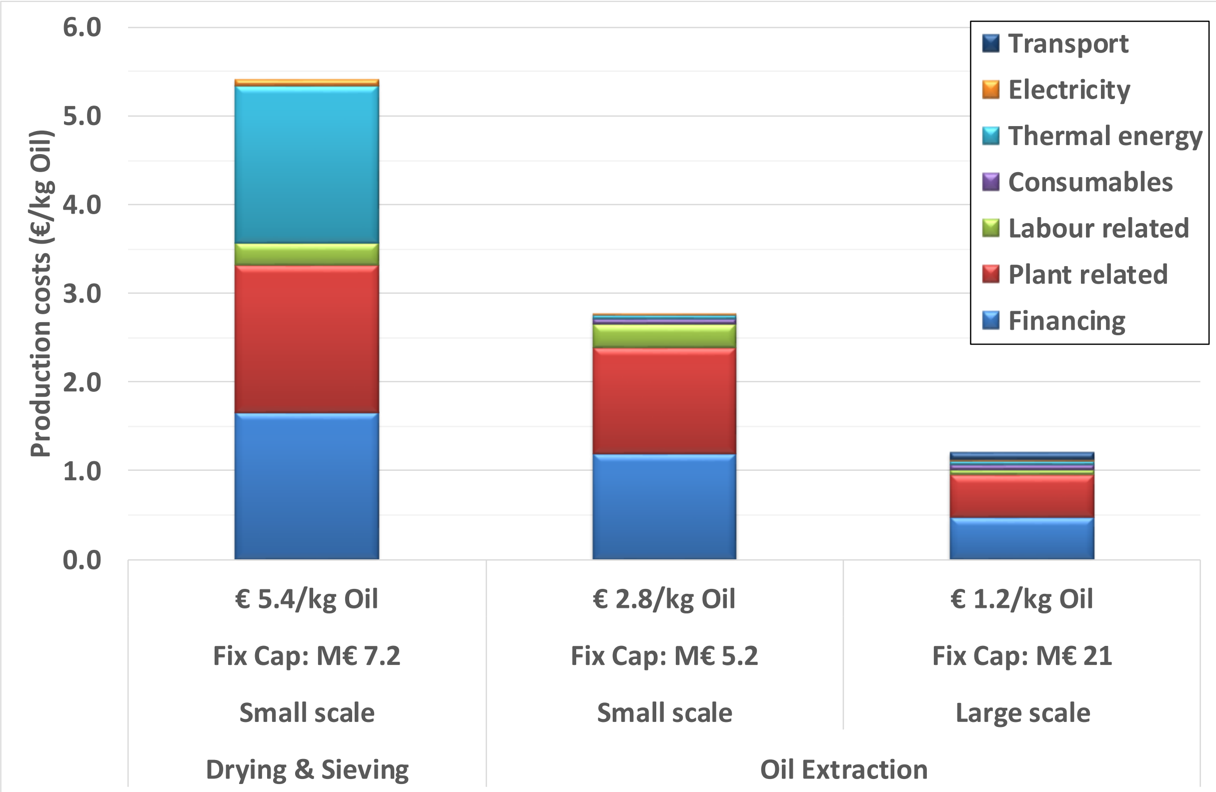

Figure 11: Production costs of tomato seed oil. Drying & sieving at small scale, oil extraction at small scale (single processing plant) or large scale (dried seeds of 10 processing plants). All costs are expressed per kg oil obtained.

6.2.6 Estimated costs of carotenoids extraction

The processing costs for the extraction of carotenoids from tomato peels are displayed in Figure 12. The costs for the drying of the material are much higher in this case, because they are displayed as costs per kg of carotenoids and the amount of carotenoids produced per ton of side stream is much lower than in the oil-case. The heat integration issue that has been described in the tomato seed oil case applies here as well and the impact on the product cost price becomes even more apparent in this situation. The costs for the extraction of carotenoids from the dried peels contributes to approximately 1/3 of the total costs (drying + extraction) on small scale. The scaling factor is slightly less favourable in this situation. A ten times larger process reduces the processing costs with 40%. This is an effect of the Nano filtration step that is incorporated in this process, which scales almost linear. The impact of consumables is slightly higher as well on large scale, due to the more costly solvent that is used in carotenoid extraction processes.

Total investment of a small scale plant including extraction adds up to 15 M€. Total investment for large scale processing, 10 times a drying plant and a large scale extraction plant, adds up to 102 M€.

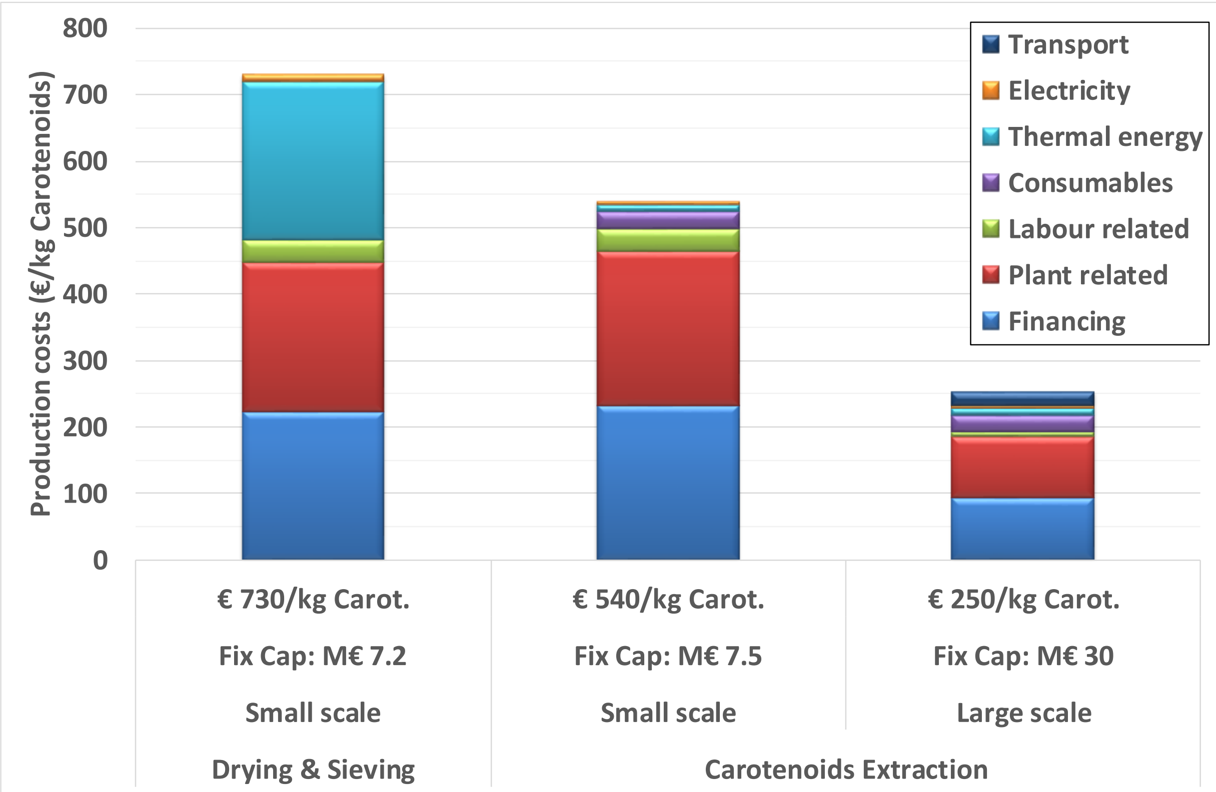

Figure 12: Production costs of tomato peel carotenoids. Drying & sieving at small scale, extraction at small scale (single processing plant) or large scale (dried peels of 10 processing plants). All costs are allocated on the cartenoids.

6.2.7 Economic evaluation

The costs of the production of oil and carotenoids from the tomato side streams are compared with the expected revenues of the products in Figure 13 and Figure 14. The following assumptions have been used in this comparison for the revenues: Oil: € 3/kg, Carotenoids: € 1000/kg, Residue (feed) € 0,25/kg.

Total investment of a small scale plant including the two extraction processes adds up to 20 M€. Total investment for large scale processing, 10 times a drying plant and two large scale extraction processes, adds up to 122 M€.

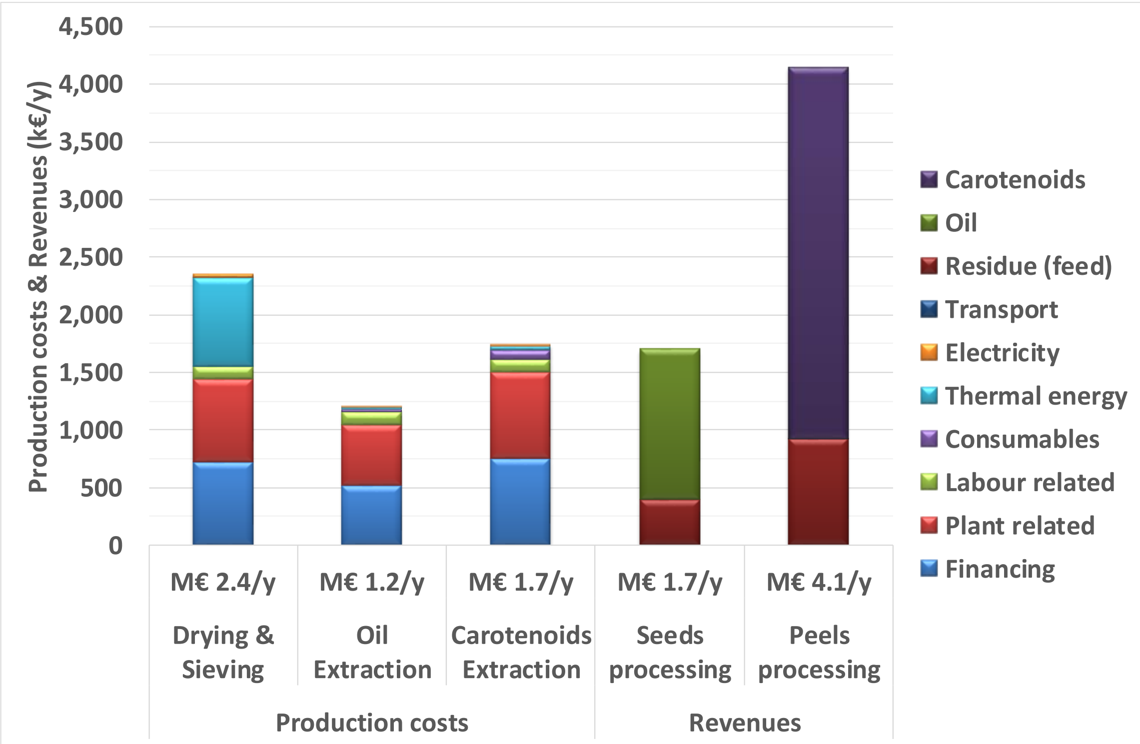

Figure 13: Costs and revenues of tomato side stream valorization on small scale (single tomato processing plant)

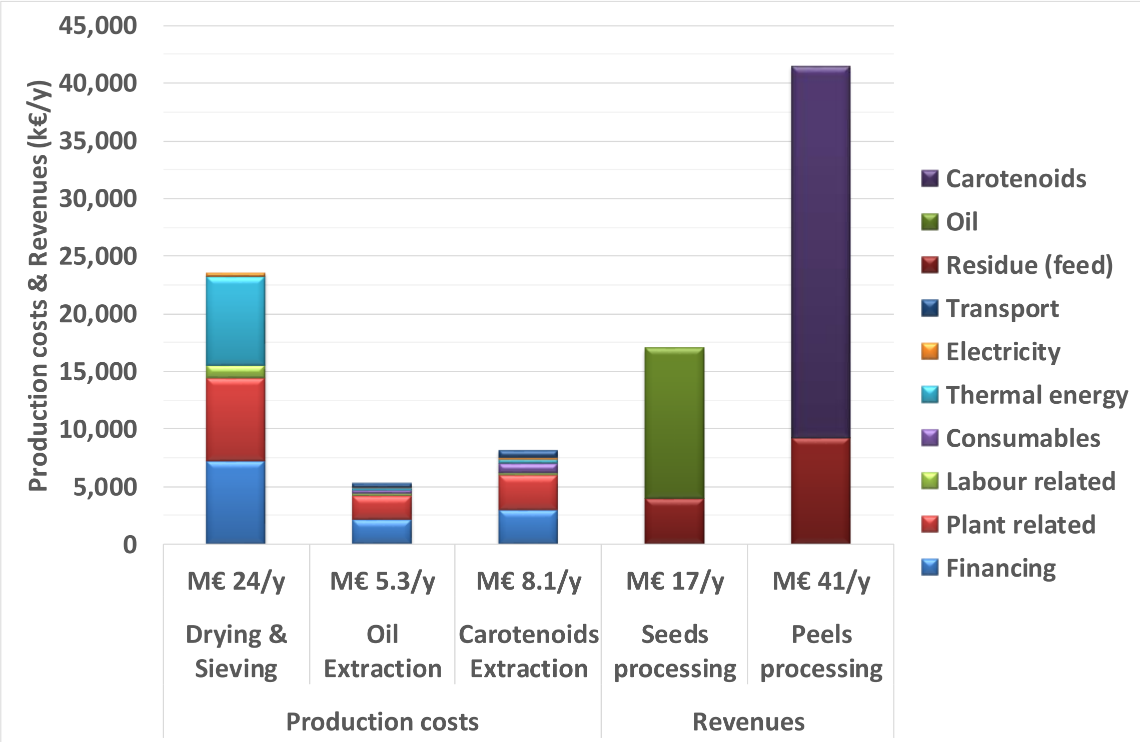

Figure 14: Costs and revenues of tomato side stream valorization on large scale (oil and carotenoid extraction from dried seeds and peels from 10 tomato processing plants)

The results show that at small scale the total processing costs are M€ 5,3 /y and the revenues are M€ 5,8 /y. At large scale the total processing costs are M€ 37 /y and the revenues are M€ 58 /y. The gross profit is relatively larger on large scale.

Remarks:

- The prices found in literature have a relatively large scatter (see chapter 5). The conclusions above are based on the prices mentioned at beginning of section 6.1.3. The business is much weaker for the lowest prices mentioned.
- The current global markets for tomato seed oil and carotenoids. For instance, the current global market for carotenoids is estimated around 300 million US$ per year (https://www.credenceresearch.com/report/carotenoids-market). Already one large-scale factory may significantly affect the market situation.

Any business investmentor is expected to specifically take potential market position and market size into consideration.

7 Conclusions on producing dietary food fibres from chicory pulp

A techno-economic analysis on producing dietary food fibres from chicory pulp was presented in REFRESH D6.5. Specific conclusions from that analysis:

> "The case study – producing a food fibre from chicory extraction residues – shows that scale size is critical for producing the fibre at a competitive price compared to replacement product (dietary fibres) in the market. Actually at the volumes generated by a large chicory processing plant, Sensus in The Netherlands, sufficient volume is available to reach such scale.
>
> Because the product is a new food ingredient, it is expected that market development to full scale may take a number of years. Results show that a gradual production start may demand for a significantly higher product price (typically €0.15 per kg extra in the studied example).
>
> In the actual decision process, however, the commercial partner decided not to develop the process because the new fibre product was not deemed sufficiently superior to compete with existing fibre products unless additional (cost price enhancing processing) would be applied."

8 Discussion, conclusions and recommendations

The techno-economic analyses presented in this report and REFRESH D6.5 have shown in a number of examples that medium to high-value food ingredients can be produced at competitive prices from streams that are currently treated as waste or used for feed. Critical factors for production plans include:

- **scale size** of the processing plant (intensive processing generally requires capital-intensive processing; economies of scale are very relevant then);
- in order to feed the large-scale plant, sufficient **supply from** a **local** or from **regional waste streams** is essential (in case collection from larger distances is needed to attain sufficient scale sizes, transportation costs may significantly raise the total costs of production, as shown in REFRESH D6.11);
- **co-production of multiple products** according to principles of biorefinery is found essential for feasible extraction of high-value products (high-value components + bulk fraction, like oil + feed from tomato seeds shown in this report and natural carotene + yellow oil in palm oil refinery, analysed in EU-RESFOOD);

Next to efficient and effective production, the value and market position of the products is essential. Most obviously the value of an existing reference product is taken. However, some proviso are appropriate:

4. When recognized as a '**natural product**' the plant-derived ingredients may have a premium price compared to synthetic variants, like for vanillin and carotenoids. Market demand for natural food ingredients is rapidly growing.

5. Although market demands for natural food ingredients are growing, product **prices may vary**, and especially when producing volumes that are large compared to the current global production they may go down. This will affect the business case.

6. **Product quality** and other attributes may play a role in product pricing. Especially a food waste derived product may significantly differ from the reference products (which are often derived from homogeneous, application-oriented materials). The quality waste material – not specifically optimised for the product – may result in suboptimal products. On the other hand, the sustainable sourcing may induce added value for certain markets.

Altogether, this report demonstrates that the broadly recognized conception that food waste (more specially food processing side streams) are adequate sources for high value food ingredients can be realized in profitable business.

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