Chapter

Recovery and Valorization of Tomato By-products in R&D EU-funded Projects

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Abstract

In the last years, the European Commission has been funding numerous projects regarding the valorization of food wastes. Tomato by-products received great attention especially in Spain, Italy, Greece, and Portugal due to high volumes and high concentration of valuable compounds. Among 40 funded projects about the management of tomato wastes in general, 14 projects are strictly connected to the valorization and exploitation of the tomato residues/by-products after processing and are of great interest for their scientific, technical, and economical outcomes. They received an overall budget of around 37 M€ over 35 years, involving 20 European and 4 non-European countries, with project coordinators located in Germany, the Netherlands, and Italy in most of the cases. This chapter delivers general information about these projects, assessing and reporting scientific and technical results. Moreover, the interconnection is highlighted among them by focusing on the contribution they gave to the European know-how, the management of the by-products and the progress they reached in waste minimization and valorization. Finally, the industrial and environmental outcomes of these projects have been reported by highlighting issues and problems that are still to be overcome.

Keywords: tomato by-products, waste valorization, European Union, funded projects

1. Introduction

In the last years, the European Commission has been funding projects regarding the valorization of food wastes. Tomato by-products received great attention especially in Spain, Italy, Greece, and Portugal due to high volumes and high concentration of valuable compounds. Among 40 funded projects about the management of tomato wastes in general, 14 projects are strictly connected to the valorization and exploitation of the tomato residues/by-products after processing and are of great interest for their scientific, technical, and economical outcomes. They received an overall budget of around 37 M€ over 35 years, involving 20 European and 4 non-European countries, with project coordinators located in Germany, the Netherlands, and Italy in most of the cases. This chapter delivers general information about these projects, assessing and reporting scientific and technical results. Moreover, the interconnection is highlighted among them by focusing on the contribution they gave to the European expertise, the

management of the by-products and the progress they reached in waste minimization and valorization. Finally, the industrial and environmental outcomes of these projects have been reported by highlighting issues and problems that are still to be overcome.

2. Funded projects

The Community Research and Development Information Service (CORDIS) [1], namely the European Commission's primary source of results from the projects funded by the EU's framework programs for research and innovation, was used to gather all information such as project factsheets, participants, reports, deliverables, and links to open-access publications about tomato by-products valorization. In the first instance, from research in this database, it came up that on 352 funded projects including the keyword "TOMATO" only 10% take into consideration wastes or by-products produced by harvesting, transformation, and use of this vegetable. In particular, the research on CORDIS with "TOMATO" and "WASTE" as keywords gives forty projects as a result. Other searches with other keywords were conducted with less significant results: for example, "TOMATO" and "VALORIZATION" give 9 projects as a result, or "TOMATO" and "RESIDUE" return 23 projects as a result. As it is possible to see from **Figure 1** the number of funded projects in this field of application had a strong increase in the last 5 years, probably due to the growing interest, shown by academia and industries, in waste reduction, valorization of materials so far considered as undesirable by-products, and exploitation of the high-value compounds contained in these waste streams.

Then, these forty projects were deeply studied, and it was possible to divide them into eight categories regarding the topic:

- Production of bioplastic from tomato residues
- Extraction of high-value compounds from residues
- Production of food additives from residues
- Production of biogas from residues

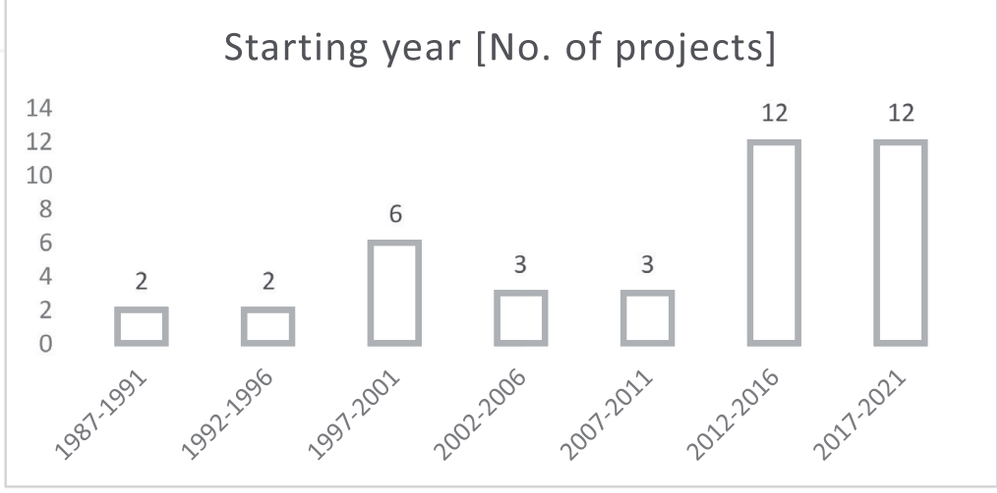


Figure 1.
Distribution during last years of funded research projects on tomato waste.

- Biorefining of residues
- Harvesting optimization
- Shelf life of processed tomato
- Other (not included in the previous categories)

Figure 2 reports a bar chart of the number of projects per field of application. Among these, only fourteen projects are strictly connected to the valorization and exploitation of the tomato residues/by-products after transformation processes. In **Table 1**, the main information is reported about these projects of interest, sorted by topic.

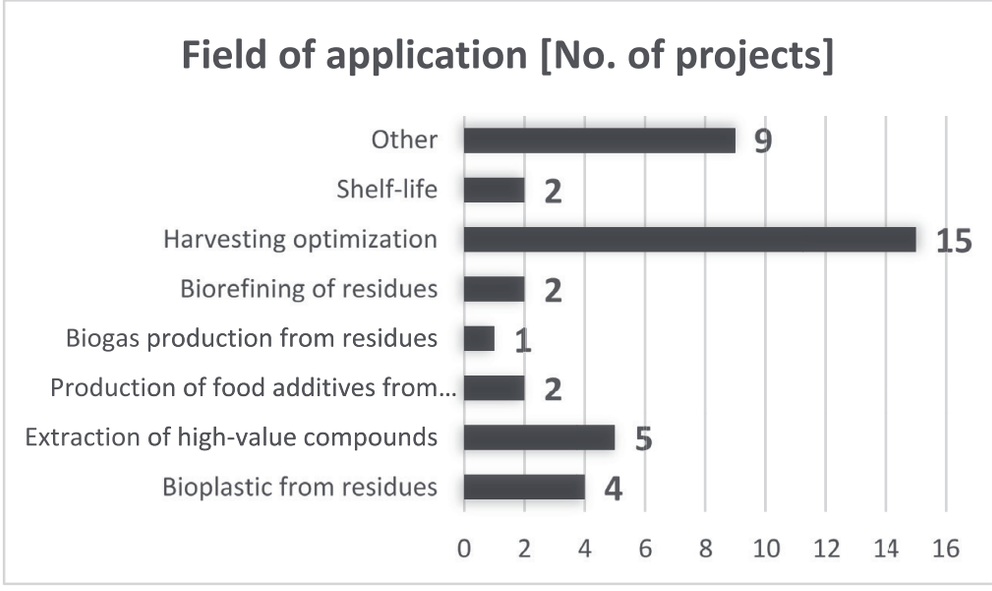


Figure 2.
Number of projects per field of application.

Acronym	Start	Duration [months]	Budget [M€]	Coordinator	Partners	Status
Bioplastic production						
BIOCOPAC	2011	33	1	SSICA (Italy)	10	✓
BIOPROTO	2014	24	0.2	IIT (Italy)	—	✓
ECOFUNCO	2019	33	5.6	CNISTM (Italy)	17	Ongoing
TOMAPAINT	2020	24	3	TOMAPAINT SRL	—	Ongoing
Extraction of high-value compounds						
QLK1-CT-2000-2041,137	2000	12	0.03	Conservas Vegetales De Extremadura (Spain)	1	✓
QLK1-CT-2000-2040,942	2000	12	0.03	Hac Le Poole (Netherlands)	1	✓
TOM	2003	24	0.9	Catchmabs (Netherlands)	8	✓

Acronym	Start	Duration [months]	Budget [M€]	Coordinator	Partners	Status
BIOACTIVE-NET	2006	24	0.6	Hochschule Bremerhaven (Germany)	7	✓
LYCOSOL	2019	6	0.07	Biocapsol (Turkey)	—	✓
Production of food additives						
QLK1-CT-2001-2042,093	2001	12	0.03	ChiPro (Germany)	1	✓
PRO-ENRICH	2018	36	3.3	Teknologisk Institut (Denmark)	15	✓
Biogas production						
*AVI*940005*	1995	30	0.1	Universität Stuttgart (Germany)	2	✓
Biorefining						
REFRESH	2015	48	9.4	Wageningen University (Netherland)	26	✓
AGRIMAX	2016	48	15.5	Iris Technology (Spain)	29	✓

Table 1.
Main information about funded European projects on valorization and exploitation of tomato wastes.

The information reported in the previous table was analyzed and summarized in the next chart to synthetically show the distribution of budget and participants among the considered application categories (**Figure 3**).

The overall budget is around 40 M€ involving 20 European and 4 non-European countries, with project coordinators located in Germany, the Netherlands, and Italy in most cases. It is worth notice that the field of biorefining, the one in which this thesis is involved, even if it is not the one with the highest number of the funded project, exhibits the highest budget and is the one with more partners involved. It is so probably because, even if the application of the biorefinery concept to tomato residual

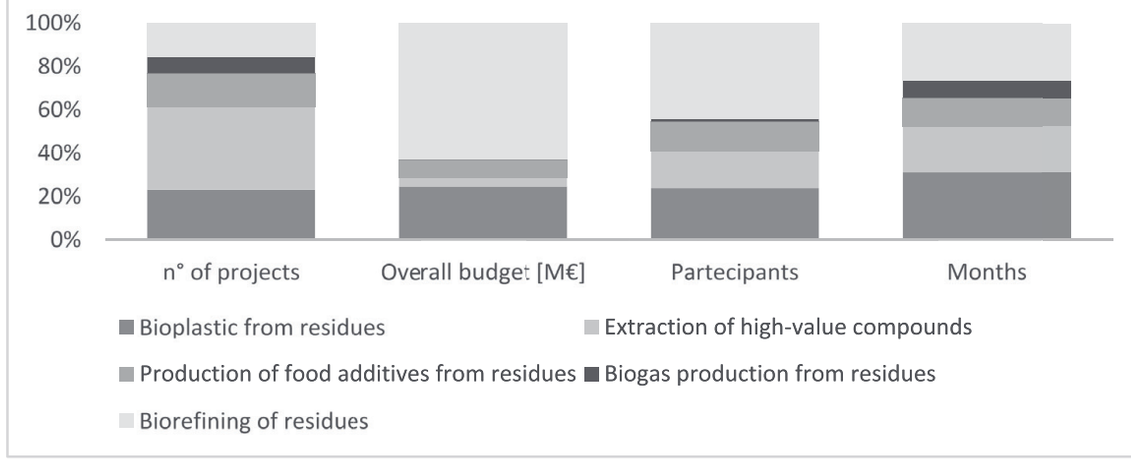


Figure 3.
Distribution of budget and participants among the considered application categories.

by-products is quite new, the European Commission believes that research in this field could strongly increase the EU technological level. In the next paragraph, the outcome of these projects will be reported and briefly discussed.

2.1 Early projects

Projects funded before 2001 lack results reports, for different reporting policies of the European Commission. Anyway, the project QLK1-CT-2000-2041,137 had likely as an outcome a patent EP1676888B1 entitled Method of obtaining lycopene from tomato skins and seeds [2], assigned to *Conservas Vegetales de Extremadura* SA, which was the coordinator of the project. The patent refers to a process for obtaining lycopene from tomato skins and seeds. The carotenoid is obtained after a series of steps of dehydration, seed separation, pelletization, extraction, distillation, and crystallization. The extraction solvent is hexane and the purity of the lycopene obtained is between 65% and 85%, depending on the raw material.

2.2 TOM

The title of the project was "Development of new food additives extracted from the solid residue of the tomato processing industry for the application in functional foods." Partners of the TOM project had developed and optimized an extraction process whereby lycopene is extracted in tomato seed oil from tomato plant processing residue. This can then be used in functional food products and cosmetics. The carried-out process involves the use of supercritical carbon dioxide (CO_2) [3]. The yield in tomato seed oil is 3–6%. The lycopene yield depends on raw material and ranges between 15 and 180 ppm, which is very low considering the extraction yield nowadays.

2.3 Bioactive-net

The title of the project was "Cultivation and processing of tomato, olive, and grape are the main agricultural businesses in the South European countries. Production of tomato paste, olive oil, and grape" and the main objectives of the project were:

- Create a broad information platform for dissemination of research results and state of art regarding the extraction of bioactive compounds from tomato, olive, and grape processing residues as well as their application facilities in the food and cosmetic industry

- Implement dissemination workshops in the South European countries aimed at transferring expertise and evaluating economic feasibilities of the extraction

- Strengthen the European market on natural ingredients

Remarkable was the study on the best available technologies (BATs) to separate vitamins, antioxidants, essential oils, and other valuable compounds from the processing residues. In *Guida pratica sui COMPOSTI BIOATTIVI ottenibili dai SOTTOPRODOTTI della TRASFORMAZIONE DEL POMODORO* they reported the main technologies available for: residues drying, lycopene extraction, and lycopene purification. Moreover, an economic assessment that compares solvent and supercritical extraction for this compound was reported [4]. The report clearly shows from

an economic and technological point of view that supercritical CO_2 is rarely favorable, while solvent extraction is profitable only when a high amount of tomato by-products is processed.

2.4 Lycosol

The title of this 2019 project is "Feasibility Analysis on the Extraction of Lycopene from Tomato Peel through Organic Synthesis." LycoSOL project proposes an environmentally friendly solution based on natural ingredients. The method involves extracting and processing healthy ingredients from the waste from food processing. The project aims to develop the process of extraction and encapsulation from plant waste, targeting production from tomato peels. No results reports or scientific papers have been already disseminated.

2.5 Pro-enrich

The title of this 2018 project is "Development of novel functional proteins and bioactive ingredients from rapeseed, olive, tomato and citrus fruit side streams for applications in food, cosmetics, pet food." Pro-Enrich was aimed at optimizing existing biomass fractionation technologies and validating novel extraction approaches beyond the current state of the art with reference to the Technology Readiness Level (TRL) assessment system (i.e., from TRL2 through to TRL 4/5) to isolate and purify proteins, polyphenols, and dietary fibers and pigments. The products being targeted are food ingredients, pet food, cosmetics, and adhesives. These were to be developed through an iterative process of feedstock mapping, laboratory process development, functionality/performance testing of samples by upscaling to pilot plant and industry level. Rapeseed, tomato peels and citrus waste were studied in the project. First, a review paper on waste composition and edible protein extraction for the selected feedstock was published [5]; then, a first pilot plant for protein production from rapeseed was started [6]; finally, the following bioactive ingredients were successfully extracted, and are waiting for Scale-up to demonstration scale:

1. Hesperidin (flavonoid/antioxidant) from citrus peels after juice production. It has market and applications in:
   Pharma: In diosmin/hesperidin products for its venotonic activity.
   protection, anti-cellulite, and more.
   Cosmetics: In products for alleviation of eye wrinkles.
   Feed: As antioxidant supplementation for pets and horses.

2. Lycopene (carotenoid/antioxidant) from tomato peels after canned food production. It has market and applications in:
   Pharma: for prostate health.
   Food: As a coloring agent in food and drink products.
   Nutraceuticals: In dietary supplements for heart and brain health, sunburn protection, and more.
   Cosmetics: In anti-aging products and for healthy skin appearance.

3. Rapeseed protein (isolate >90% wt. protein and concentrate >50% wt. protein) from rapeseed press cake after rapeseed oil and biodiesel production. It has market and applications as a replacement for:

Food: animal-based protein.
Pet food: animal-based protein.
Adhesives: petrochemically derived phenolics up to 40%.

2.6 BIOCOPAC

The title of the project is "Development of bio-based coating from tomato processing wastes intended for metal packaging." BIOCOPAC initiative looked at tomato by-products to satisfy some of these needs. The goal was to develop a natural lacquer liner for tins that are made from the cutin raw material contained in discarded tomato skins. The coating was aimed to be applied to internal and external surfaces of food tins to ensure consumer health and safety. The next step was to develop the bio-resin and the lacquer. Scientists developed two different formulas to produce the lacquer, one specifically designed for tinplate and a generic one for all types of metal can. BIOCOPAC produced canned goods using these lacquers, demonstrating that the lacquer performs as well as current products. An interesting outcome of the project is a Life Cycle Assessment (LCA) conducted using the SimaPro software, version 7.1. The analyses compared the LCA of a conventional epoxy-based lacquer to a bio-lacquer, tomato cutin based, obtained from tomato processing waste. The results showed clear environmental benefits of the "Bio-lacquer." The benefit of the cutin lacquer lies in the saving of natural resources and the recovery of part of the skins. This can lead to lower consumption of fossil fuels and lower CO_2 emissions.

BIOCOPAC project merged with the BIOCOPAC+ project, funded under LIFE+ Environment Policy and Governance project application (Grant Agreement No. LIFE13 ENV/IT/000590). The project was started on the 1st of June 2014 and lasted for 36 months. The project was industry-driven and focused on demonstration activities aimed to prove the technical feasibility and effectiveness of the cutin extraction and production systems currently developed at a laboratory scale. Its outcomes were a prototype pilot plant for cutin extraction, installed at *Azienda Agricola Virginio CHIESA* (IT) and a cutin-based lacquer production site in SALCHI (IT) plant [7].

2.7 BIOPROTO

The project title is "Bioplastic production from tomato peel residues." The team investigated the possibility of creating a bioplastic film from discarded tomato skins. The idea proved feasible, yielding scalable and biodegradable options for food packaging. Results yielded a new set of films and coatings taken from the lipid portion of plant cuticles, reported in **Figure 4**. The outcome also represented a potentially scalable and cheap process for the manufacture of bioplastics intended for use in food packaging. BIOPROTO's new plastic was biodegradable, with minimal environmental impact [8].

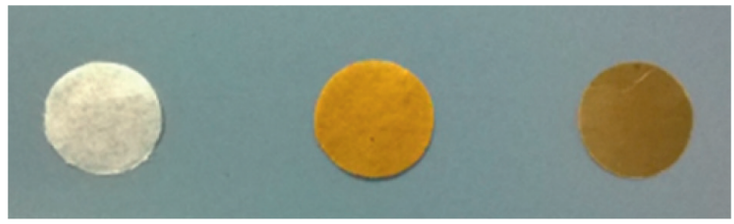


Figure 4.
Photographs of bioplastic made by tomato cuticle during the BIOPROTO project.

2.8 ECOFUNCO

The tile project is "ECO sustainable multi-FUNctional biobased COatings with enhanced performance and end-of-life options." The overall objective of project ECOFUNCO [9] was to select, extract and functionalize molecules (proteins, polysaccharides, cutin) from highly available, low valorized biomass such as tomato, legumes, sunflower, etc. for the development of new bio-based coating materials to be applied on two different substrates (i.e., cellulosic and plastic-based), with improved performances compared to currently available products and at the same time with the more sustainable end of life options. The products to be developed in the project were in particular:

- Antimicrobial-antioxidant coatings based on chitin nanofibrils, and/or chitosan, for cellulose tissues (personal care), paper and cardboard (packaging for fresh products like pasta, tableware), woven and nonwoven (sanitary), plastic substrates (bio-polyesters) for active packaging

- Cutin-based formulations for water-repellent coatings (paper cups, service paper, etc.), water vapor barrier (packaging), and protective properties (non-food packaging)

- Protein-based barrier adhesive for multilayer food packaging (bio polyesters based), with sustainable end-of-life options (composting, recyclability).

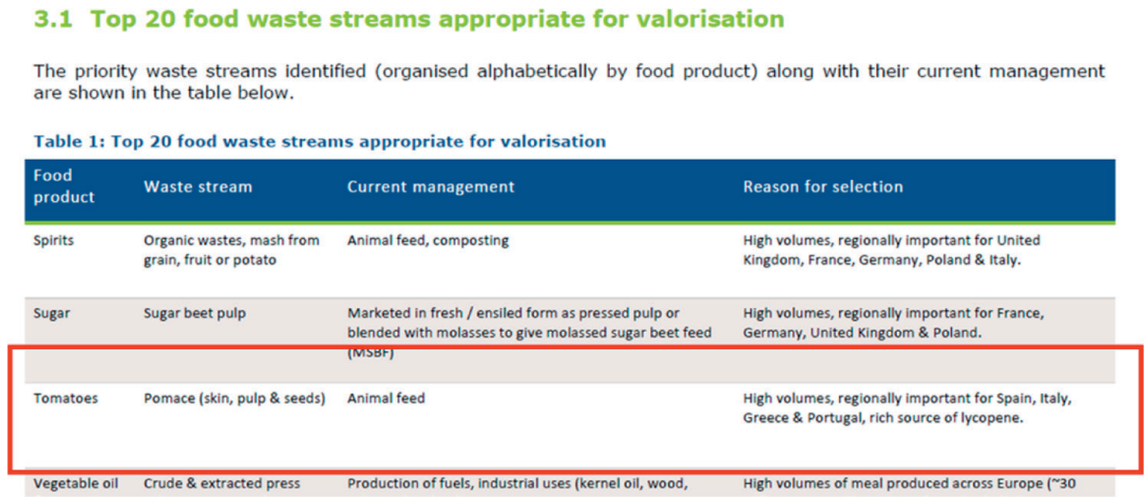
The ECOFUNCO project final event has been taken on June 17–18, 2022 in the form of "1st Conference on Green Chemistry and Sustainable Coatings."

The event confirmed that the ECOFUNCO project developed sustainable bio-based and compostable coatings to be applied on bioplastics and cellulose substrates to reach the same properties as fossil-based packaging materials. Also, the use of nanofibrils to add antimicrobial properties to tissues has been demonstrated.

The ECOFUNCO coordination and management demonstrated a great mind opening and a forward-looking sensitivity as they dedicated a session of the final conference to other related EU-funded projects, that is, FISH4FISH, PRESERVE, RECOVER, PROLIFIC, and Agrimax, in order to foster the cooperation between European projects.

2.9 Refresh

The title of the project is "Resource Efficient Food and dRink for the Entire Supply cHain." The overall aim of the REFRESH project was to significantly contribute toward the objective of reducing food waste across the EU by 30% by 2025 and maximizing the value from unavoidable food waste and packaging materials. The project aims to gather information about the main and most present food waste in the European countries, find the known way to exploit these by-products, and create a simplified tool to help the decision-maker to valorize at best these side streams, both in terms of economic feasibility and environmental impact. Tomato by-products are one of the considered waste streams. The project outcomes are 6 scientific publications regarding food waste, from their management to their reduction, a website and a software tool [10]. One of the main outcomes of the REFRESH project is a deliverable with the TOP20 waste streams in Europe, carefully reporting



3.1 Top 20 food waste streams appropriate for valorisation

The priority waste streams identified (organised alphabetically by food product) along with their current management are shown in the table below.

Table 1: Top 20 food waste streams appropriate for valorisation

Food product	Waste stream	Current management	Reason for selection
Spirits	Organic wastes, mash from grain, fruit or potato	Animal feed, composting	High volumes, regionally important for United Kingdom, France, Germany, Poland & Italy.
Sugar	Sugar beet pulp	Marketed in fresh / ensiled form as pressed pulp or blended with molasses to give molassed sugar beet feed (MSBF)	High volumes, regionally important for France, Germany, United Kingdom & Poland.
Tomatoes	Pomace (skin, pulp & seeds)	Animal feed	High volumes, regionally important for Spain, Italy, Greece & Portugal, rich source of lycopene.
Vegetable oil	Crude & extracted press	Production of fuels, industrial uses (kernel oil, wood,	High volumes of meal produced across Europe (~30

Figure 5.
Tomato pomace is one of the TOP20 food wastes in Europe.

their current management and the reason for selection. Tomato by-products are in the list (see **Figure 5**).

Another main outcome is FORKLIFT, a spreadsheet learning tool that applies a partial lifecycle greenhouse gas impact and costing calculation approach for six key examples of unpreventable food processing co-products, by-products, or wastes (collectively referred to as *side flows*):

1. Apple pomace
2. Pigs blood
3. Brewers spent grains
4. Tomato pomace
5. Whey permeate
6. Oilseed press cake

FORKLIFT allows users to interpret the results of the effects of intervention while making it possible to compare the results with alternative products available on the market [11]. For tomato pomace conventional solutions for its exploitation were selected and modeled in the FORKLIFT® tool, allowing for evaluation via LCA and LCC, cost and CO_2 emission for different scenarios of valorization, and to easily compare them as a support to decision making. **Figure 6** shows the interface of the tool. In the analysis of tomato pomace, the following valorization routes were considered:

- Lycopene production
- Preparation of fodder
- Anaerobic digestion
- Land spread

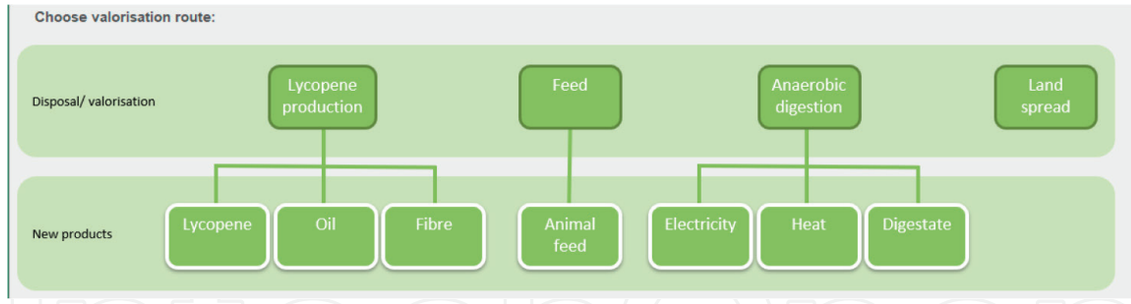


Figure 6.
Valorization routes available on the FORKLIFT spreadsheet.

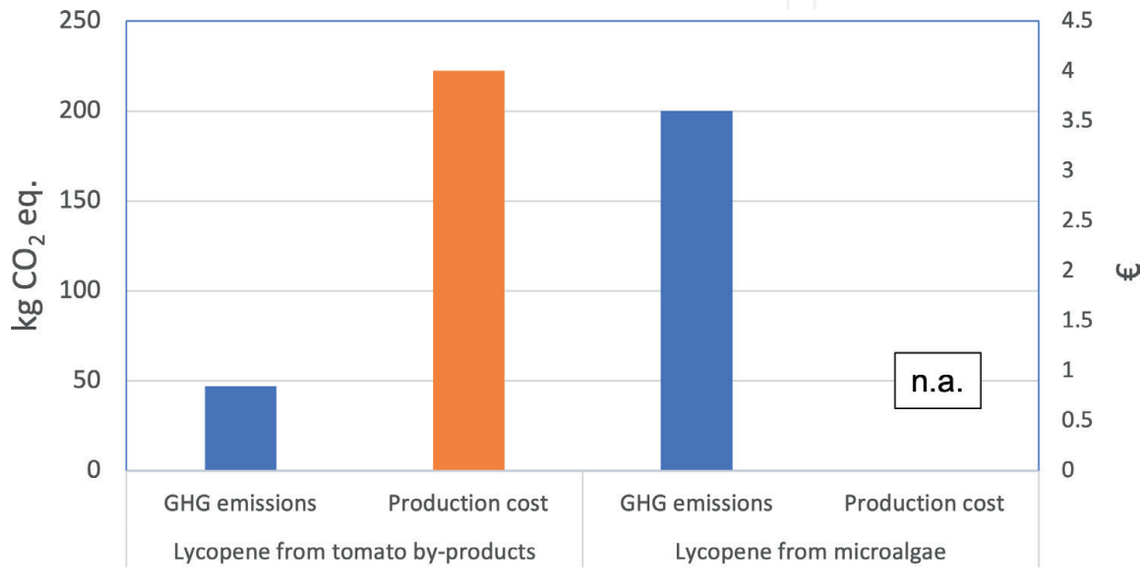


Figure 7.
FORKLIFT output for lycopene production.

For example, with this spreadsheet is possible to compare lycopene production cost and emission with carotenoid production from microalgae (**Figure 7**).

2.10 AGRIMAX

The project title is "Agri and food waste valorization co-ops based on flexible multi-feedstocks biorefinery processing technologies for new high added value applications." The goal of the project was to extract the significant amounts of valuable compounds contained in food industry wastes, AgriMax [12] combined affordable and flexible processing technologies for the valorization of side streams from the horticultural culture and food processing industry to be used in a cooperative approach by local stakeholders. The project merged previous knowledge and outcome of other European projects, such as cutin extraction and exploitation studied in the BIOCOPAC project. LCA and LCC studied the best approach to minimize the environmental impact of the new value chains. Moreover, a pilot multi-feedstock bio-refinery process was set up at two demonstration sites in Spain (Pilot Plant at Indulleida S.A.) and Italy Pilot Plant (at Chiesa Virginio EC). Currently, the Italian pilot plant is valorizing the tomato by-products, producing cutin bioplastic, a small amount of lycopene and compost. The pilot plant flowsheet is reported in **Figure 8**.

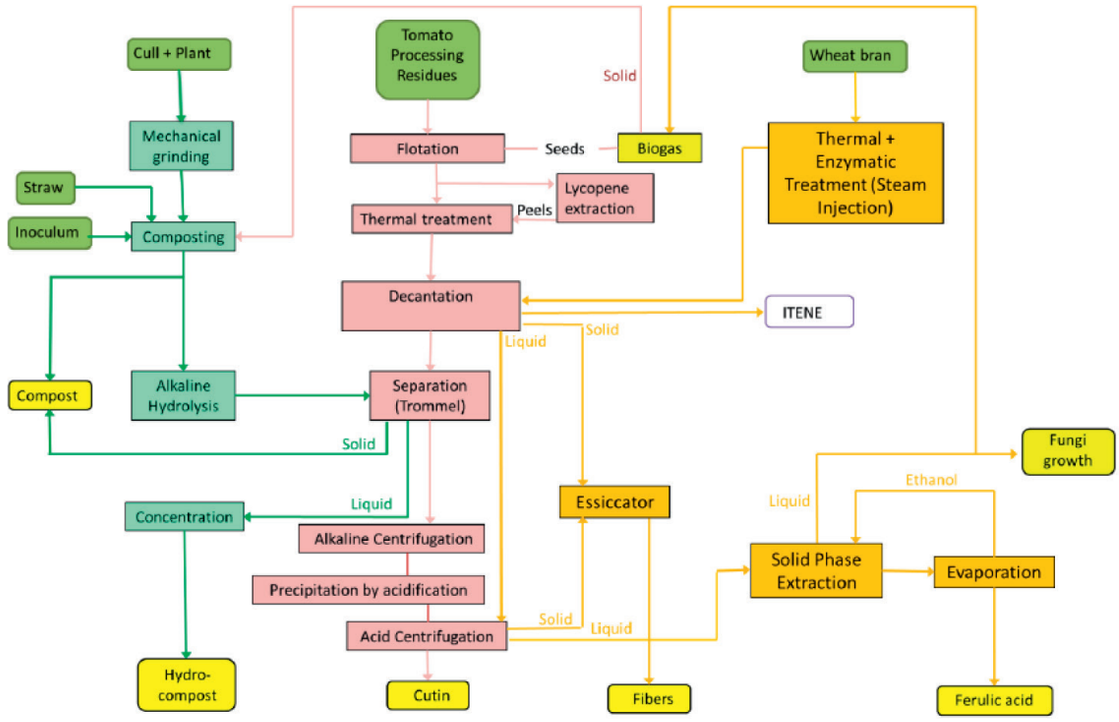


Figure 8.
Flowsheet of Italian pilot plant located in the factory of Azienda Agricola Virginio Chiesa, Canneto Sull'Oglio (MN), Italy.

3. Conclusion

In conclusion, 11% of funded European projects having tomato as a topic are dealing with tomato wastes and by-products. Forty projects were found when searching CORDIS with "tomato" and "waste" as keywords; 14 regard by-products valorization, categorizable in the following topics: production of bioplastic or biofilm, extraction of high-value compounds, preparation of food additives or fodder, biogas production via fermentation and biorefining of tomato by-products. The overall budget, that European Commission furnished to the participants, has been around 40 M€ in about 35 years. These projects involved 130 participants coming from all over the world. Extraction of compounds is the topic of most projects, but the highest budget has been awarded to biorefining. This is also the main focus of the research activities first explored and then directly pursued by the authors [13, 14] of this chapter. Projects on extraction technology development had as an outcome the optimization of commercial techniques, leading to patents; moreover, some studies showed that supercritical CO_2 is never economically feasible for lycopene extraction. PRO-ENRICH is the only project about food additives that were recently found, to start a pilot plant for protein production from different waste streams, including tomato pomace. In the last years, bioplastic production from tomato by-products received great attention and funding, leading a pilot plant in Italy to produce metal packaging cover with a biofilm obtained from tomato peels. Recent projects (AGRIMAX and REFRESH) aim to best exploit food waste, making recourse to a biorefining approach. Main problems remain in the tomato by-products valorization: the high economic or environmental cost of lycopene extraction, as also underlined [15] by the authors of this chapter; the absence of a 'green' alternative for cutin extraction, and the difficulty in finding a biomass

similar to tomato pomace in order to overcome the seasonality issue. Moreover, a lack of data, studies, and projects on energy recovery from tomato by-products was evidenced by the present survey.

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