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Posted Date: 21 April 2023

doi: 10.20944/preprints202304.0726.v1

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Promoting Sustainable Agricultural Waste Management and Industrial Symbiosis through an Innovative Web Platform

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Abstract: Sustainable bio-economy is considered to be one of the most promising routes towards the transition to a circular and climate-neutral economy. The valorization industry of bio-waste and agri-food by-products represents a key player in bioeconomy. In this article the design and the development of a web platform aiming at promoting synergies enabling the agricultural waste valorization is presented. The platform consists of: (i) the AgriPLaCE Waste Management Database which provides the users with an extended list of potential utilization measures for a variety of agricultural waste streams (ii) the AgriPLaCE Synergies Tool which aims to create synergies between different actors involved in the value chain from agricultural waste production to waste treatment and new valuable products' exploitation. At the initial stage, the conceptual design of both tools took place by conducting an in-depth analysis for the user needs and services alongside the system architecture. Following, the AgriPLaCE platform development stage took place, with the implementation of all the necessary subsystems. The results showed that multiple potential collaborations can arise by the use of the AgriPLaCE platform, while users can also deepen on alternative and emerging treatment technologies and valuable products that can derive from a wide range of agricultural waste streams.

Keywords: agricultural waste; bio-waste; synergies; web platform; bioeconomy; industrial symbiosis; waste management

1. Introduction

In the recent years, there is a great need in Europe for the development of a bio-based industry. The EU aims to form an economy with zero greenhouse gas emissions by 2050 as a commitment to the global climate action under the Paris Agreement [1–4]. The transformation of the society to a climate-neutral one is a serious challenge for a better future. All parts of society and economic sectors will play a role with bio-based product sector having the most significant one [5]. The European Parliament emphasizes the need to encourage investments in the development of a sustainable bioeconomy where fossil-intensive materials are replaced with renewable and bio-based ones because it is believed that a switch to sustainable materials will play a significant role in the transition to a climate-neutral economy [6]. One of the most promising routes to a resource-efficient circular economy is towards bio-products and bio-based value chains. Such a "valorization and value-addition" strategy involves a complex web of actors and processes, promoting socioeconomic development, environmental advantages, and technological advancements.

The biowaste and agri-food by-products valorization industry represents a key player in bioeconomy. Given their origin, biodegradability and non-toxicity, the bio-based products are of special interest for the modern chemical industry and their market is going to increase up rapidly (from 72 to 135 billion € from 2021 to 2028) [7]. This novel approach generates a new concept of waste recovery that becomes part of the entire productive process i.e. a waste becomes the feedstock for the successive production of other products, i.e. the bio-refinery concept [8]. Those processes should be

 doi:10.20944/preprints202304.0726.v1

led with possibly high effectiveness and in closed circulation of CO_2 with the ultimate goal of optimizing the use of land and food security through sustainable, efficient (effective), raw and largely limiting the amount of agri-food industrial processing wastes. The process of developing a biorefinery system necessitates significant capital investments in technology and installation, as well as the assurance of suitable staff, raw material, and logistical backdrop.

Moreover, there are still obstacles that are frequently of a non-technical nature, such as a lack of confidence and cooperation between the participating stakeholders, incomplete knowledge (knowledge gaps), a lack of or strict environmental regulations, and unprofitable waste-to-resource exchanges, which include end-of-life processes like collection, sorting, and recycling. Several tools have been created in recent years to get around some of these obstacles. Existing tools were categorized into different types depending on their facilitation approach in a recent literature review of information systems aiding the discovery of industrial symbiosis [9].There are five of them: (1) open online waste markets, (2) facilitated synergy identification systems, (3) industry sector synergy identification, (4) social network platforms and communities, and (5) tools to identify potential waste-to-resource exchanges at the industry sector level [10]. They represent digital environments for businesses to find and establish partnerships for waste-to-resource exchanges.

As an example, to our study, the total production of fresh tomatoes in the European Union has increased from 2000 to 2016 by 10.7% while the consumption of fresh tomatoes showed a slight decrease, nevertheless still being the most consumed vegetable [11]. In contrast, demand for food products that reflect a Mediterranean lifestyle and include tomatoes as an ingredient is predicted to cause a slight increase in the consumption of processed tomatoes. Consequently, as overall production and consumption of tomato increases, so also does the quantity of tomato wastes and by-products derived from primary production and processing, thus leading, in the next years, to increasing disposal problem for stakeholder of tomato value chain. However, tomato by-products are still rich in important nutrients, such as proteins, lipids, carbohydrates, and fibers, and constitute a primary source of several carotenoids, whose global market has exhibited, in the last decade a tremendous growth, which is expected to reach around US$ 2.29 billion by 2027, with a compound annual growth rate (CAGR) of 4.1% [12].

In this context, the sustainable valorization of tomato waste and by-products at an industrial scale is necessary. This can be applied through their conversion in a gamut of novel, naturally-derived food ingredients and additives, which can be efficiently used as functional ingredients in food, feed, nutraceuticals, cosmetics and pharmaceutical products. Additionally, energy will be produced from no recyclable residue materials, thus pursuing the “total use” concept.

As mentioned earlier, the agri-food sector represents one of the most important economic sectors in terms of turnover, value-addition and employment. Nevertheless, sector’s competitiveness is fast decreasing and faces challenges coming both from the customers’ preferences for healthy eating, organic products, high quality food products and environment’s challenges towards sustainable production. Moreover, this sector is mainly characterized by many micro and traditional agri-food businesses finding it difficult to access research and knowhow to support innovation and promote new products, able to cover the market needs and increase their competitiveness on regional, national and international markets, especially in the case of small and medium-sized enterprises (SMEs). On the other hand, EU has recognized the crucial role that SMEs, representing 98% of the European food industry, can play in developing resource-efficient and cost-effective solutions to secure sufficient supplies of safe, healthy and high-quality food, by developing productive, sustainable and resource-efficient primary production systems and recovering competitive and low-carbon supply, processing and marketing chains.

According to the position of the European Parliament [13], in order to protect, preserve and improve the quality of the environment and public health, waste management should be improved and transformed into sustainable material management, promoting the principles of the circular economy, enhancing the use of renewable energy, increasing energy efficiency, providing new economic opportunities and contributing to long-term competitiveness. In order to achieve the construction of a truly circular economy, additional measures on sustainable production, by focusing on the whole life cycle of products in a way that preserves resources and closes the loop must be taken. Highlighting residues as a valuable material will provide greater independence in terms of raw material import needs and will create important opportunities for local economies and stakeholders, to strengthen the circular economy's compatibility with energy, climate, agricultural, industry, and research policies, as well as to benefit the economy and the environment through reductions in greenhouse gas emissions.

In this context, the creation of a platform that deals with the utilization of agro-waste is the subject of many recent studies [14,15] and some platforms including news in agricultural waste and sustainable agriculture have been formed (e.g., SAI, Agrovalor, AgroCycle project) [16–19]. Moreover, the Food and Agriculture Organization of the United Nation, provides free and unrestricted access to 22 databases (e.g. FAM, FAOSTAT, AGRIS, AGROS) containing statistical data on food, agriculture, and sustainable management of natural resources [20–22]. However, despite the fact the agriculture is the major pillar on the national economy, no systematic effort is observed to provide the required information, especially as far as farmers are concerned, in an ever-changing era [23].

The purpose of this study is the development of an electronic platform in order to promote synergies for the utilization of agricultural waste in the production of secondary materials. This platform will contribute to the analysis of processes and requirements per potential user (waste provider e.g., farmer, recovery technology provider, end user of waste e.g., plastics industry), the planning of the processes and connections between the users that will be carried out, the technological development of the platform, the test operation and demonstration operation of the platform. The platform will execute logical rules to match users' roles and needs by recommending waste producers or end-users according to their own needs. These rules will be developed based on each user's profile and their activity on the platform. Also, a data base including an extensive bibliographic content regarding the type of agricultural waste (e.g., leaves, fruit, bark, etc.) produced by plant production in the Greek territory and could potentially be raw materials in the circular economy will be available through the platform. The aim is to cover 50% of the cultivated area of Greece (excluding the crops of industrial plants, aromatic plants and fodder plants). The new platform will operate as a tool for networking & exchange of expertise & knowledge, it will encourage innovative thought processes, within the chain-actors and other external stakeholders, to foresee the complexities and performance needs of the value chain, thereby minimizing risks and challenges to the conceptual process system.

Under this frame, it is essential an industrial symbiosis simulation subsystem to be developed allowing industrial symbiosis in a manner similar to the prementioned circular based strategy. Particularly, in this study, we integrate the strategy of industrial symbiosis repositories to expand the capability of the collaboration platform. We narrow our attention to the waste-to-resource matching subsystem in particular and explain how a database engine makes it possible for it to interact with the other parts of the collaboration platform. We also offer use cases based on plastic and agri-food industry waste (tomatoes cultivation waste streams) to illustrate how this database engine works. The overall objective was to present a novel platform matchmaking conceptual framework that was intended to be used in a market for waste valorization pathways. This platform would give access to the users to both quantitative and qualitative data and would aid in decision-making. This conceptual framework will assist primary producers and agri-food industries to find an alternative way to valorize their waste streams and on the same time it will assist the potential end users to find ecofriendly raw materials to develop innovative and under the frame of circular economy products.

2. Materials and Methods

2.1. Conceptual design

Given the large number of agricultural waste produced daily, it is crucial to develop means to re-utilize these products and inspire Synergies among suppliers and demanders. In this section, the methodology followed in order to develop the conceptual design of both AgriPLaCE Waste

 doi:10.20944/preprints202304.0726.v1

Management Database and AgriPLaCE Synergies Tool are presented. In particular, the aim of the AgriPLaCE Waste Management Database is to provide users with information about (i) the common treatment methods of different agricultural waste streams in Greece, (ii) the economic activities and processes producing different agricultural waste streams and mainly (iii) to provide information regarding alternative agricultural waste management solutions and emerging managements techniques and finally (iv) the industrial sectors that could utilize the products deriving from the application of the alternative and emerging treatment techniques. On the other hand, the aim of the AgriPLaCE Synergies Tool is to create synergies between different actors involved in the value chain from agricultural waste production to waste treatment and new products exploitation. However, the conceptual base of both tools is the same taking into consideration that there is a common waste stream categorization and terminology and both are addressing the following user categories: waste suppliers (WS) and waste demanders (WD). At this point, it has to be mentioned that the physical persons behind the role of WS could be any industry or enterprise representative owning vegetable or fruit residues. So, besides farmers, also food industry representatives, fruit and vegetable retail trade representatives and HORECA representatives could be covered by this user category. On the other hand, owners of agricultural waste treatment technologies and industrial and enterprise representatives who would like to develop technologies to produce products derived from agricultural waste, could be covered by the role of WD. In the following paragraphs, the study of the conceptual components and their connection between each other in both tools is presented.

Waste streams categorization definition

The root of the conceptual design was based on the assumption that each user category (WS or WD) demands information from the other user category in order to cover their needs. For example, the WS wants information related to the WD, in order to find out how their waste could be exploited and the WD wants information regarding which WS could provide them with waste that could be exploitable by them. Consequently, the need for a common waste stream categorization vocabulary arose. To address this, it was necessary to investigate the agricultural waste streams as they are generated by the WSs and also, to investigate the agricultural waste streams specifications as they are required by the WDs in order to be able to receive the waste. The findings showed that rejections in agricultural fields could be categorized per kind of fruit/vegetable plants and then sub-categorized in leaves, stems, twigs and fruits/vegetables unsuitable for human consumption. Regarding the rejections in the food industry and in the HORECA sector, the stream rejections could be parts of the fruits/vegetables like pits/kernels/seed, peels and fruits/vegetables unsuitable for human consumption. Finally, regarding the rejections in the retail trade of fruits and vegetables, these could be unsuitable for human consumption. From the other side, the waste streams that could be exploitable by the WD could be constituted by:

-only one part of **one** specific kind of fruit/vegetable (kernel from apricot, peels from tomato, seeds from lemon) → (stream category "a")

-one part of **more than one or all** kinds of fruit/vegetable plant/s (e.g. twigs from all kinds of fruit and vegetable plants, or fruits/vegetables unsuitable for human consumption deriving from all kinds of fruit/vegetable plants) → (stream category "b")

-a total of different parts of **more than one or all** registered kinds of fruit/vegetable plants (leaves, twigs and seeds from all kinds of fruit/vegetable plants) → (stream category "c")

So, it was necessary that all cases of waste streams be captured to cover the needs of both WSs and WDs. To achieve this, the waste stream categorization adopted was the following:

Table 1. Waste classification in AgriPLaCe Platform.

Kind of fruit/vegetable	Waste type (part of fruit/vegetable plant)
Kind 1	peels pits/kernels/seed twigs leaves stems

 doi:10.20944/preprints202304.0726.v1

	fruits/vegetables unsuitable for human consumption
Kind 2	….
………..	……

By the use of filters in the AgriPLaCE Waste Management Database, the user is able to "compose" the waste stream/s for which they would like to have information, according to their willing. For example, they can filter by type of waste (e.g. seeds and peels) and view results for a waste stream including seeds and peels from all registered fruit and vegetable plants (see Section 2.2.3).

On the other hand, in the case of the AgriPLaCE Synergies Tool, the users -during their profile registration- are allowed to "compose" different waste streams categories, according to their willing. This can be achieved either by selecting kind of fruit/vegetables from a drop-down list and then waste type (part of fruit/vegetable plant) or by selecting only waste type/s (parts of fruit/vegetable plant) regardless of the kind of fruit/vegetable (see Section 2.2.4).

Waste streams origin

The economic activity, the industrial sector and the processes generating different agricultural waste streams were investigated. Based on this study, information regarding the waste stream origin is provided per waste type (part of fruit/vegetable plant) of each kind of fruit and vegetable, in the AgriPLaCE Waste Management Database. This is achieved by both mentioning the NACE (the Statistical Classification of Economic Activities in the European Community) code/s of the economic activity/ies generating the different waste streams and also by providing information about the process generating each waste stream (e.g. food processing). By the use of filters, the user can view results for selected NACE codes or processes.

Regarding the AgriPLaCE Synergies Tool, when WSs register their profiles, they have to select from a drop down list the industrial sectors where they belong. The list was created based on the same study mentioned above. Consequently, the waste streams registered by WSs are connected with the sector generating them.

Agricultural waste treatments methods for bio-products creation

Regarding the agricultural waste treatment methods for valuable bio-products creation, two categories were taken into consideration. Those are:

- The established and frequently applied waste management methods in Greece; and
- The alternative agricultural waste management solutions and emerging management techniques.

Information of both categories are provided in the AgriPLaCE Waste Management Database. While the aim of the project was to promote the alternative agricultural waste management solutions and emerging management techniques, the common waste management methods in Greece (such as biogas, pellet, animal food etc.) are also provided per waste type (part of fruit/vegetable plant) for each kind of fruit and vegetable, due to the fact that there are still a lot of agricultural waste streams that are not exploited even in conventional ways and are just discarded.

However, the main part of the study was focused on defining the alternative agricultural waste management solutions and emerging management techniques. A lot of information was extracted from the literature review, regarding innovative already applied and emerging technologies for the treatment of the agricultural waste stream category "a", "b" and "c".

Sectors that could act as end-users for the products derived from the alternative agricultural waste management solutions and emerging managements techniques

The products derived from the methods described above could have a wide range of applications in different industrial sectors like the food, cosmetic and pharmaceutical industry, polymers production, energy etc.

Through the AgriPLaCE Waste Management Database, the sector of end-use is connected with each treatment technology, which is connected with each waste type (part of fruit/vegetable plant) of each kind of fruit and vegetable. As in other cases too, the user can use filters to view the information they desire for selected end use sectors.

Regarding the AgriPLaCE Synergies Tool, when WDs register their profiles they have to select from a drop down list their industrial sectors. The drop-down list of the WDs industrial sectors contains the sectors related to:

-the agricultural waste treatments methods for bio-products and also

- the sectors that could act as end users for the products derived from the alternative agricultural waste management solutions and emerging managements techniques.

In this way, the waste streams registered by WDs are connected with the sectors that could exploit them.

2.2. AgriPLaCE Platform Development

The completion of this research mentioned above has led to the development of the AgriPLaCE platform, an electronic system aiming to aid users with waste management applications. The AgriPLaCE platform represents the described methodology implemented into an online platform for guiding decision-makers to review existing or develop new waste management strategies and form new synergies. The platform is accessible through the following link: https://www.agriplace.gr/. The tool was implemented considering the latest technologies in web development, through the use of open-source platforms, offering flexible access through mobile devices and personal computers so as to allow easy access and use from any user, from any device connected to the internet.

The AgriPLaCE platform offers an open waste management database tool for users providing a detailed catalogue for utilization of specific types of agricultural waste, as well as a synergies tool that operates as a host for industrial symbiosis networks by providing means of communication among users with matching profiles. During the implementation of the AgriPLaCE platform the following methodological phases were followed:

1. Preliminary conceptualisation of the actual methodologies, phases and steps of the tools. During this stage a conceptual model of the AgriPLaCE platform was prepared.
2. Preparation of PDF/PPT documents with expected visuals of the tool. Once the general concept was agreed, the desired output was drafted in electronic format.
3. Enrichment of the methodologies in PDF/PPT documents and development of wireframes. Based on the agreed flows and models, the content of each methodology, phase, and steps was integrated in the electronic documents depicting in more detail the actual AgriPLaCE platform content.
4. Drafting of mock-ups. Upon completion of the above phases a draft prototype of the actual tool and the included methodologies, phases, steps, has been outlined.
5. Mock-ups revision and finalization. All mock-ups were discussed and review as needed.
6. Development of the AgriPLaCE framework. The completion of the mock-ups was followed by the actual development of the AgriPLaCE platform.
7. Deployment of the AgriPLaCE platform release candidate version. A fully functional version has been deployed and provided for testing and further contribution.
8. Validation exercise: A validation exercise with the technical partners was organised. All comments were incorporated to the final release.
9. Final release of the AgriPLaCE platform.

2.2.1. AgriPLaCE Platform System Architecture

The subsystems comprising the AgriPLaCE platform stack follow a simple and intelligent architecture consisting of three layers i.e., i) the Presentation layer, ii) the Application layer, and the iii) Database layer [24], as depicted in Figure 1.

 doi:10.20944/preprints202304.0726.v1

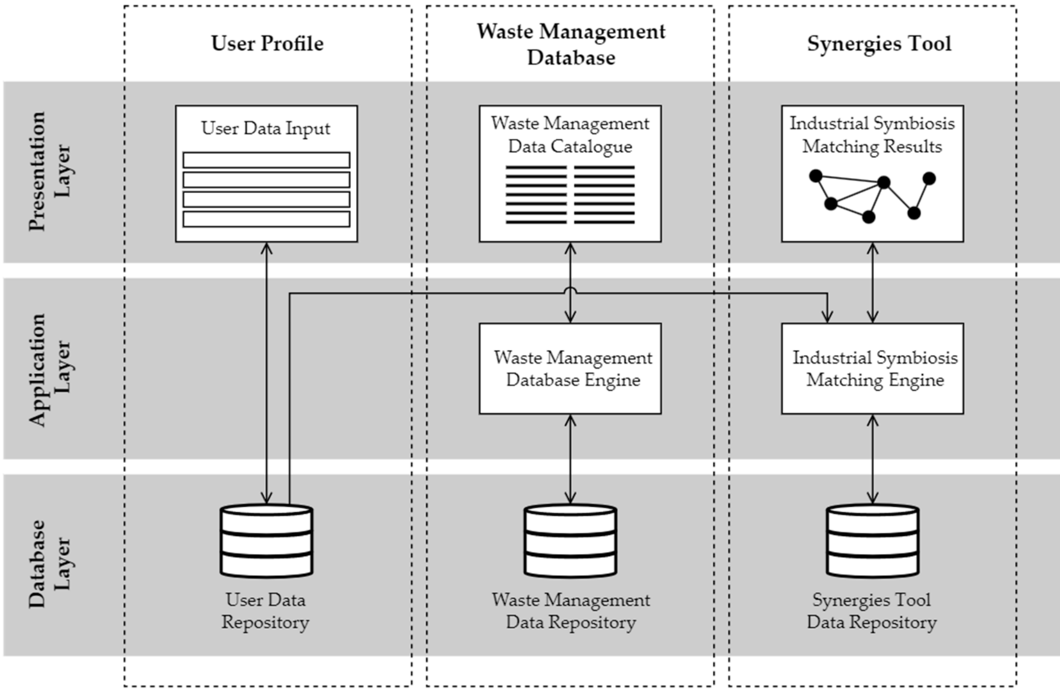

Figure 1. The AgriPLaCE System Architecture.

The user interacts with the platform by way of the Presentation layer, which provides all necessary user interfaces for performing the tools' functionalities. Every action in the system triggers an operation on the Application layer. Conversely, when the user requests information by performing the relevant actions in the Presentation layer, the Application layer retrieves any relevant data from the Database layer, transforms it to the appropriate format, and then sends it to the Presentation layer to present the data to the user.

The Presentation layer is using javascript with VueJS as the primary framework and additionally, Vuelidate for model-based validation and Vuetify framework for the components. Vuetify is a complete user interface framework built on top of Vue.js. The goal of this approach is to provide the AgriPLaCE platform with all the necessary features needed to build a rich and engaging user experience. Additionally, Vuetify takes a "mobile first" approach to design, which means that the platform just works out of the box—whether it's on a phone, tablet, or desktop computer.

The Application layer incorporates the Laravel Framework, a free and open-source PHP web framework intended for the development of web applications. In that manner, the web application dynamically interacts with the user providing faster and smoother transitions making the website feel more responsive [25].

The Database layer encompasses a PostgreSQL database for computational operations [26]. PostgreSQL is a free and open-source relational database management system that operates as a data repository for the user input data, the waste management catalogue data and the synergies tool data.

The server is the physical container that hosts the AgriPLaCE platform and makes available to the public all its functionality. On the server resides the NGINX and the Apache HTTP web server software hosting all the platform's layers. NGINX is used as a reverse proxy server for handling static content requests and Apache as the backend to serve dynamic content, offering enhanced server performance for the web platform. Each web server software has Docker containers installed to provide all the software infrastructure to host the platform. The AgriPLaCE docker contains a standard unit of software that packages-up the AgriPLaCE code and all its dependencies in order for the application to run quickly and reliably from one computing environment to another [27].

 doi:10.20944/preprints202304.0726.v1

2.2.2. AgriPLaCE User Profile

To access the full functionality of the AgriPLaCE platform, users are prompted to register to the website by submitting relevant information regarding their waste management needs. Apart from login details they are requested to provide their enterprise type and geographical location, as well as information regarding their waste supply or needs. These data are stored in the User Data Repository and used in the Synergies Tool for calculation of the Industrial Symbiosis Matching. Based on the information stored in their profile, the users will be able to view a ranked catalogue of potential waste management partners and contact them through the Synergies Tool of the AgriPLaCE platform.

2.2.3. AgriPLaCE Waste Management Database

The AgriPLaCE Waste Management Database provides an extended list of potential utilization measures for a variety of agricultural waste types and acts as a catalogue for waste management application for its users. The Database is open to the public and users do not have to be registered to the platform to access it. The list provides detailed information related to the waste, specifically:

1. Kind of fruit or vegetable;
2. Waste Type;
3. Process generating waste;
4. Economic activity from which the waste originates (NACE2);
5. Conventional ways of waste management;
6. Emerging ways of waste management;
7. Products deriving from conventional and emerging waste managements;
8. Economic activity (NACE2) and industrial sectors valorizing products deriving from waste;

It is possible for the database users to use filters and perform an advanced search for their waste type of interest by typing keywords in the search field. The algorithm then re- categorizes the results based on the specific filtering provided. Finally, users are able to download their search results in a .xls file format for further editing.

2.2.4. AgriPLaCE Synergies Tool

The AgriPLaCE Synergies Tool is accessible only for registered users. Upon registration users are asked to provide information related to their waste supply or demand needs. This process occurs in the user profile subsystem which stores the user data input in the User Data Repository. Once the registered user enters the Synergies Tool page, the Industrial Symbiosis Matching Engine calculates the priority of each user profile stored in the user data repository and sorts all users based on their assigned priority.

Upon calculation, the user is presented with a sorted list of potential industrial symbiosis matches. Results (other platform users) with the same priority value are shown alphabetically and the user can further categorize them by performing advanced search of the results with the use of filters and search by keywords. The engine then re-categorizes the results based on the specific filtering provided and presents the updated list to the user. It is also possible to download the industrial symbiosis matching list in a .xls file format for further editing.

Finally, the Synergies Tool hosts a means of communication for registered platform users through its Contact module. Specifically, after matchmaking it is possible for the user to send a message through the platform that reaches the receiver via e-mail. The receiver’s e-mail is shared only in case of reply, thus complying with GDPR principles.

2.3. Industrial Symbiosis Matching Algorithm

Industrial Symbiosis Matching Engine of the Synergies Tool encompasses the profile matching algorithm which is based on weighted variables in a weighted sum model [28,29]. Specifically, there are five indexes used for ranking the potential matching of two users. Each index is assigned with

 doi:10.20944/preprints202304.0726.v1

one variable which receives the value 1, in case two users have a common index value and 0, in case the users have different index values.

The priority calculation formula is:

$$a \cdot K + b \cdot W + c \cdot R + d \cdot U + e \cdot M = P, \quad (1)$$

where K, W, R, U, M are the index variables, a, b, c, d, e are the weights of each variable and P is the priority value.

The five indexes and the respective variables and weights are presented in Table 1.

Table 2. Synergies Tool indexes with respective variables and weights.

Index	Variable	Weight
Kind of fruit or vegetable	K	a = 0.35
Waste type	W	b = 0.35
Region	R	c = 0.10
Regional unit	U	d = 0.10
Municipality	M	e = 0.10

The priority calculation matrix, based on the index variable values is presented in Table 2.

Table 3. User matching priority matrix based on index variable value.

Priority	K	W	R	U	M
1	1	1	1	1	1
0.90	1	1	1	1	0
0.80	1	1	1	0	0
0.70	1	1	0	0	0
0.65	0	1	1	1	1
0.55	0	1	1	1	0
0.45	0	1	1	0	0
0.35	0	1	0	0	0
0.30	0	0	1	1	1
0.20	0	0	1	1	0
0.10	0	0	1	0	0
0	0	0	0	0	0

Users receiving a higher priority value are then classified as more suitable candidates for waste transaction and appear higher on the Synergies Tool matching list. Users receiving the same priority value are then listed alphabetically.

Users can be waste suppliers, demanders or both based on the information they have stored on their profile. The Synergies tool provides two independent lists:

- Suppliers List, presenting waste suppliers matching the user's waste demands
- Demanders List, presenting waste demanders matching the user's waste supplies.

In case the user falls under only one category e.g. is a waste supplier, the waste supplier list shall perform the exact same algorithm showcasing the user's competition based on the same criteria.

3. Results

3.1. Results related to AgriPLaCE Waste Management Database

The extended literature review resulted in the identification of a large variety of alternative and emerging agricultural waste treatment technologies which can produce valuable materials that could find application in a wide range of industrial sectors. All these emerging agricultural waste treatment

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technologies descriptions are provided to the users through the AgriPLaCE Waste Management Database. The user is able to view information related to waste treatment technologies for waste streams of his interest (see waste stream category "a", "b" and "c" in Section 2.1) or in contrary, to be informed which stream categories ("a", "b" and "c") could be treated by waste treatment technologies of his interest. This way, both user categories (WS and WD) can cover their needs for specific information.

The agricultural waste treatment methods that were identified through literature review are the following and are connected to the waste stream categories ("a", "b" and "c" as follows):

-Valuable components extraction processes (Connected to "a" waste stream category). These could be for example different oil types extraction processes from peels and kernel of lemon, orange and other fruits or vegetables; extraction of lycopene from tomato peels; pectin extraction from watermelon peel; chlorogenic acid, vanillic acid, ferulic acid from the pear peels and a lot of other valuable ingredients extraction processes from different waste streams.

-Biochar production (Connected to "c" waste stream). Biochar is produced by a process called carbonisation. This process involves pyrolysis in the absence of oxygen. The pyrolysis process has been used on small and industrial scales to produce biochar from residual forest and agricultural biomass, hence fruit and vegetable waste can be used for biochar production.

-VFAs production (Connected to "b" waste stream). Fruit and vegetable waste (flesh) can be used as a raw material for the production of VFAs. VFAs are chemical building blocks, which are globally demanded by the chemical industry. Due to their functional groups, they are suitable precursors necessary for the production of chemicals such as biopolymers, PHAs (polyhydroxyalkanoates), PLAs (polylactide), ketones, esters, alcohols, aldehydes, alkanes and biofuels such as CH_4 and H_2.

-PHA and PLA production (bioplastics) (Connected to "b" waste stream). Traditionally, bioplastics have been produced from food crops such as corn starch, tapioca roots or sugar cane, but in recent years, many processes have been extended to produce bioplastics from bio-waste including flesh of fruit and vegetable waste.

-Insect protein production for animal feed (Connected to "b" waste stream). There are many varieties of insects that are used for human consumption and animal feed, so mass production of edible insects for animal feed seems to be a viable way to meet the demand for animal protein. Regarding the feed to be fed to farmed animals, restrictions have been established by the competent EU policy makers. In this context, insects intended for farmed animals feed must be fed exclusively with materials of plant origin. Therefore, fruit and vegetable waste (flesh) could be used as raw material for insect farming.

-Production of "green" building materials (Connected to "c" waste stream). Certain types of agricultural waste, such as leaves, stems and branches, could be used as a source of fibres to reinforce building materials such as panels or for the production of biocomposites.

-2,3-butanediol production (Connected to "c" waste stream). 2,3-Butanediol (BDO) is a valuable chemical building block with a wide variety of applications in areas such as chemical, energy, food and polymer production. The industrial production of this compound is carried out by chemical methods from fossil sources and requires high energy intensity and the use of expensive catalysts. 2,3-BDO is an alcohol that can be produced by fermentation of sugars derived from a wide range of plant raw materials: garden waste, vegetable and fruit waste (fruits, stems, leaves and branches).

-Microalgae production for animal feed (Connected to "c" waste stream). The use of fruit and vegetable waste (flesh) could be applied to the production of micro-algae. Fruit and vegetable flesh is a rich source of nutrients necessary for the growth of algae.

3.2. Results related to the AgriPLaCE platform's Synergies Tool

To illustrate the functionality of the AgriPLaCE platform's Synergies Tool, a hypothetical use case of five potential users (one waste supplier and four waste demanders) is presumed, where the main user is a waste supplier (WS) seeking potential partners (waste demanders) in need for the supplied waste (WD 1, 2, 3 and 4). Each user has provided information on their profile upon

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registration, where they have selected their needs from a given list of items. For the Synergies Tool, the functionality is based of five indexes, where the users have selected the values presented in Table 3.

Table 3. Use Case of a waste supplier and four waste demanders index values.

Index	WS	WD 1	WD 2	WD 3	WD 4
Kind of fruit or vegetable	Tomato	Tomato	Pepper	Tomato	Melon
Waste type	Seeds	Seeds	Seeds	Seeds	Rind
Region	Attica	Attica	Attica	Attica	Attica
Regional unit	Piraeus	Athens Central	Piraeus	Piraeus	Piraeus
Municipality	Perama	Athens	Piraeus	Perama	Perama

These data are extracted from the User Data Repository and fed to the Industrial Symbiosis Matching Engine as inputs to perform calculations. Based on the common index values between the waste supplier and each waste demander, each potential collaboration pair receives a binary value on each index variable. The index variable matrix for each potential pair is presented in Table 4.

Table 4. Use Case of a waste supplier and four waste demanders index variable values.

Variable	WS - WD 1	WS - WD 2	WS - WD 3	WS - WD 4
K	1	0	1	0
W	1	1	1	0
R	1	1	1	1
U	0	1	1	1
M	0	0	1	1

The next steps for the engine are to calculate each demanders priority for the given supplier profile and sort the Synergies Tool list based on the users with the highest priority ranking. The flow diagram of the use cases for the user priority calculation and Synergies Tool list sorting is depicted in Figure 2.

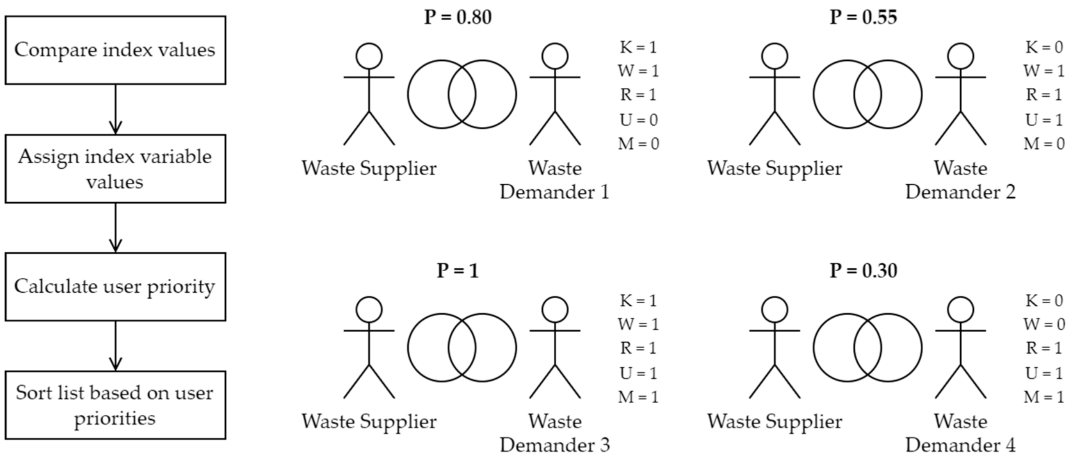

Figure 2. Synergies Tool functionality flow for use case scenario.

On the left side of Figure 2, the flow diagram of the Industrial Symbiosis Matching Engine algorithm is depicted, while on the right side the user profile data are compared and index variables take the value 1, when the respective index values are the same, and the value 0, when the respective index values are different. In these cases, the priority equations are calculated as follows:

$$0.35 \cdot 1 + 0.35 \cdot 1 + 0.10 \cdot 1 + 0.10 \cdot 0 + 0.10 \cdot 0 = 0.80 \quad (2)$$

 doi:10.20944/preprints202304.0726.v1

$$0.35 \cdot 0 + 0.35 \cdot 1 + 0.10 \cdot 1 + 0.10 \cdot 1 + 0.10 \cdot 0 = 0.55 \quad (3)$$

$$0.35 \cdot 1 + 0.35 \cdot 1 + 0.10 \cdot 1 + 0.10 \cdot 1 + 0.10 \cdot 1 = 1 \quad (4)$$

$$0.35 \cdot 0 + 0.35 \cdot 0 + 0.10 \cdot 1 + 0.10 \cdot 1 + 0.10 \cdot 1 = 0.30 \quad (5)$$

Based on these calculations, the system presents the list to the Waste Supplier sorted by the highest priority:

1. Waste Demander 3;
2. Waste Demander 1;
3. Waste Demander 2;
4. Waste Demander 4;

Apart from the use case presented in this study, the Synergies Tool has been tested with over 20 different user profiles (both waste suppliers and demanders) showcasing multiple potential users and collaborations that shall arise by the use of the AgriPLaCE platform. It is expected that hundreds of users shall register in the platform and reach numerous potential matches for waste transaction. The communication module of the Tool enables users to seek contact with collaborators by sharing their needs and creating a wide network of industrial symbiosis partnerships.

The platform is designed to be user-friendly and accessible to a wide range of industries, from small and medium-sized enterprises to large corporations. The platform is also designed to be scalable and adaptable to the needs of different industries and regions resulting in significant environmental and economic benefits. A key benefit is the reduction of waste and resource consumption. By connecting industries and enabling them to exchange resources and waste products, the platform helps minimize waste and reduce the use of virgin resources which not only reduces the environmental impact of industrial activities but also reduces costs for participating industries. The digital platform also promotes collaboration and innovation among industries by bringing together industries from different sectors and regions, enabling the exchange of knowledge, expertise, and technology. This can lead to the development of new products, processes, and business models that are more sustainable and efficient.

Furthermore, the AgriPLaCE platform can host new business opportunities. By connecting industries and enabling them to exchange resources and waste products, the platform can create new markets and revenue streams which can foster economic growth and job creation in regions where industrial symbiosis is implemented, while also promoting social and environmental justice. By enabling the exchange of resources and waste products, the platform can help reduce the environmental impact of industrial activities on local communities, hence promoting environmental justice by ensuring that the benefits and costs of industrial activities are distributed more equitably.

Finally, the AgriPLaCE platform has the potential to advance sustainable development. By enabling the exchange of resources and waste products, the platform can nurture the creation of a more circular economy that is based on the principles of sustainability, hence ensuring that industrial activities are conducted in a way that is environmentally, socially, and economically sustainable in the long term. As the platform is implemented in more regions and industries, its impact is likely to grow, leading to a more sustainable and prosperous future for all.

4. Discussion

The agricultural industry must adjust to a number of growing issues, such as dietary changes, farmworker shortages, climate change, general environmental degradation, and population growth. Digital technologies are anticipated to play a significant role in the development of solutions to these problems. Agriculture stakeholders have been using digital tools to enhance their operations more and more over the recent years [30,31]. This trend has been accelerated by the physical distance-keeping measures put in place during the COVID-19 pandemic [32]. This is reflected in the fact that the agro-food sectors increasingly combine physical and digital components (such as platforms,

 doi:10.20944/preprints202304.0726.v1

decision-support tools, and digital marketplaces) with increasing interaction between the two (such as to produce, transport, process, and deliver agro-food products to end users). Nonetheless, the drastic change prophesied by the economy digitalization has not yet fully materialized for global agriculture systems. Given the anticipated advantages of such a change, stakeholders are calling for increased efforts to promote the digitalization of agriculture, and many EU countries view the use of digital technologies in the agricultural sector as a top priority as shown by EU policies (Green deal, from Farm to Fork) to be implemented in 2023 [3,33,34].

In this context, and given the admission that "digital" machines will determine the direction of agriculture in the future based on recent research [35,36] the specific study deals with the development of a user-friendly digital platform containing an extended waste management database as well as a synergies tool that operates as a host for industrial symbiosis networks by providing means of communication among users.

The results of the implementation of the AgriPLaCE digital platform suggest that it has the potential to contribute to the development of a more sustainable and efficient agriculture and industry. By facilitating resource exchange and increasing efficiency, the platform can help to reduce waste and decrease the environmental impact of agricultural and industrial activities. In addition, the platform can help to improve economic performance by reducing costs and facilitating the development of new business opportunities.

The scalability of the platform is also an important feature, as it allows for the potential expansion of the platform to include more industries and resources, leading to even greater environmental and economic benefits. As the platform continues to grow and develop, it is likely that new synergies and opportunities for resource exchange will emerge, further contributing to the sustainability and efficiency of the agriculture and industry.

While the results of the evaluation were overwhelmingly positive, there were some challenges and limitations to the implementation of the platform. One challenge is ensuring the participation and engagement of all the industries in the region. While some users might be enthusiastic about the platform and its potential benefits, others might be more hesitant to share information or participate in resource exchange. This highlights the importance of continued outreach and education to promote the benefits of industrial symbiosis and the digital platform.

Another limitation is the need for ongoing maintenance and updating of the platform. As new industries and resources are added to the platform, it will be important to ensure that the database is kept up to date and accurate. In addition, continued user feedback and evaluation will be important to identify areas for improvement and ensure that the platform is meeting the needs of its users.

Author Contributions: Conceptualization, Eva Skourtanioti, Katerina Valta; methodology, Ioannis Varvaringos, Eva Skourtanioti; software, Ioannis Varvaringos, Georgios Letsos, Evgenia Rizoudi, Ektoras Makras; validation, Ioannis Varvaringos, Georgios Letsos, Evgenia Rizoudi, Ektoras Makras; formal analysis, Ioannis Varvaringos, Eva Skourtanioti, Margarita Panagiotopoulou, Sofia Papadaki.; investigation, Ioannis Varvaringos, Eva Skourtanioti, Margarita Panagiotopoulou, Sofia Papadaki; resources, Ioannis Varvaringos, Eva Skourtanioti, Margarita Panagiotopoulou, Sofia Papadaki; data curation, Ioannis Varvaringos.; writing—original draft preparation, Ioannis Varvaringos, Eva Skourtanioti, Margarita Panagiotopoulou, Sofia Papadaki; writing—review and editing, Ioannis Varvaringos, Eva Skourtanioti, Katerina Valta, Margarita Panagiotopoulou, Sofia Papadaki.; visualization Ioannis Varvaringos.; supervision, Katerina Valta.; project administration, Katerina Valta, Eva Skourtanioti. All authors have read and agreed to the published version of the manuscript.

Funding: This research has been co-financed by the ERDF of EU and Greek national funds through the Operational Program Competitiveness, Entrepreneurship and Innovation, under the special actions "Aquaculture" – "Industrial Materials" – "Open Innovation in Culture" (project code: T6ΥΒΠ-00220, MIS 5048495).

Data Availability Statement: Not applicable.

Conflicts of Interest: Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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