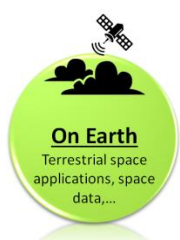
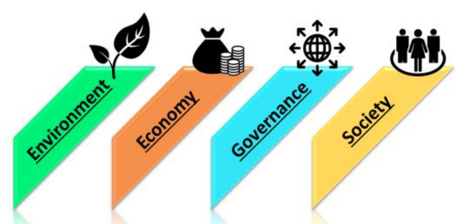
European Interparliamentary Space Conference (EISC)

European Space Agency

Space for Sustainability Award

Selected	2017 Edition





Using Satellites to Unlock Europe's Untapped Resource

Every year in Europe over 139 million tonnes of agricultural waste are produced. However, the majority of agricultural waste is currently unmanaged and unexploited. Interestingly, recent studies have shown

that agricultural waste is a valuable feedstock for the production of biochemicals. Our innovative solution is to utilise ESA’s satellite imagery to connect biochemicals-based companies to this resource through a platform that will predict agricultural waste across Europe in ‘real-time’. The project will help accelerate the transition to the sustainable bioeconomy, bring new revenue to farmers, and stimulate innovation in the biochemical sector.

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Using Satellites to Unlock Europe's Untapped Resource

Accelerating the transition to the bioeconomy

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June 2017

Every year in Europe over 139 million tonnes of agricultural waste are produced. However, the majority of agricultural waste is currently unmanaged and unexploited. Interestingly, recent studies have shown that agricultural waste is a valuable feedstock for the production of biochemicals. Our innovative solution is to utilise ESA's satellite imagery to connect biochemicals-based companies to this resource through a platform that will predict agricultural waste across Europe in 'real-time'. The project will help accelerate the transition to the sustainable bioeconomy, bring new revenue to farmers, and stimulate innovation in the biochemical sector.

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1 Introduction

1.1 Agricultural waste

Climate change, air pollution and loss of biodiversity are just some of the drawbacks associated with the use of fossil fuels. To counteract these negative aspects, Europe must transition to the so-called 'bioeconomy' – an economy where only renewable materials are converted into food, products and energy. Dedicating land for cultivating crops as a feedstock for biochemicals, is one solution to transition to the bioeconomy. However, such processes raise concerns on impacting local food security as they compete for agricultural land [1].

Appropriate carbon building blocks that do not compete with food resources, alter the ecosystem and are available in abundance must be identified. One viable option is the use of lignocellulose as a feedstock for biomaterials. Lignocellulose is a term used to describe dry plant matter; it is composed of carbohydrate polymers (cellulose) and an aromatic polymer (lignin). The primary source of lignocellulose is agricultural crop residues that remain in the field after the harvest of crops. Crop residue is one of the most abundantly available raw materials on Earth [2]. The most common residues include stalks, ears, leaves, and/or cobs (collectively referred to as stover), and/or straw associated with cereal production [3]. The properties of crop residues make an ideal carbon source for production of bioplastics, biofuels and biochemicals.

Within Europe, agricultural waste is a hugely underestimated resource. Research by Scarlat et al. suggests that within the EU alone, there are over 139 million tonnes per year of collectable crop residue available [4, 5]. The potential masses of collectable crop residues for individual EU countries are displayed in Fig. 1. The crop residue removal rate was calculated considering the requirements for sustainable soil conservation. On average between 40-50% of cereal crop residues can be successfully removed from the soil without impacting soil quality [6].

The abundant availability of agricultural waste is currently unexploited at a large scale. The major limitations of utilising the resource are the lack of an established collection, storage and handling system that is timed to coincide with biochemical production rates [7]. A successful system would avoid considerable

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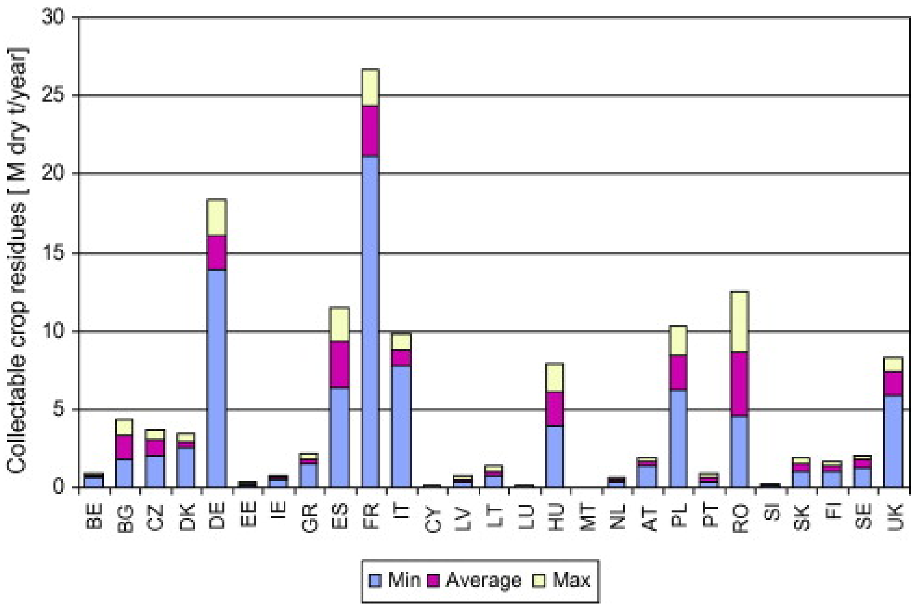

Fig. 1: Collectable crop residues for EU countries. Image adapted from Scarlat et al. [4]

storage periods and the degradation of crop residues. Crop residue production is unpredicted, due to different harvest seasons, and the quality and quantity is often irregular. Furthermore, there is a lack of incentive for farmers to deal with the crop residues as there is an unawareness of the possibility to use the waste as a resource [8]. An opportunity exists to develop a holistic approach to agricultural waste management, and in parallel, to encourage new innovative business opportunities in the biobased sector.

1.2 Satellite Imagery

The use of satellite imagery has now become ubiquitous in our daily life: from environmental and disaster response to monitoring energy and natural resources, from maritime monitoring to urban management [9]. Among the several applications in which Earth Observation (EO) has proven to be beneficial is agriculture. By using a combination of optical satellite images and multispectral instruments, it is possible to monitor parameters related to the health and maturity of the crops [10, 11]. For instance, with satellite images, one can identify the crop type, estimate the crop yields, monitor changes in soil conditions, and detect the presence of diseases (e.g. pest and blight) [12]. The data can be used to perform precision agriculture, which consists of more intensive and efficient cultivation practices. Examples include, the optimisation of fertilisers and water consumption. Moreover, satellite imagery has been proven to be an ultimate tool for illicit crop detection, drought monitoring and calamities damage assessment (e.g. storms). All of the above not only improves the farm management processes thus bringing substantial economic benefits to the farmers, but also provides governments, funds and private investors with useful data for making policies and investments.

Several companies around the world are already providing customised agricultural recommendations to farmers and many startups are entering this market because of its enormous potential in generating revenue [13, 14]. However, the focus of all these enterprises is on maximising crop yields and reducing overheads. There is a lack of attention to use satellites to manage agricultural waste, which has been shown to be a valuable resource for producing biomaterials [15, 16].

2 Solution

To unlock the currently unexploited agricultural waste, we propose an innovative **online platform** (website and mobile application) that uses remote sensing technologies and machine learning (ML) algorithms to provide a real-time map of the agricultural waste production across Europe. The platform will have a twofold scope: it will connect farmers with biochemical companies, and it will supply a holistic overview of agricultural waste. The platform would encourage farmers to manage their waste as it would constitute an additional source of income. Moreover, it would allow companies to have a clear overview of agricultural waste across Europe, thus making the resource availability more regular and predictable. Our solution would allow industries to access agricultural waste from anywhere in Europe.

2.1 Methodology

Published data available on the platform will be the results of three steps: training, prediction, and estimation of agricultural waste.

Satellite imagery and multispectral instruments data are the foundation blocks of the platform. The data can be used to analyse the health and maturity of the crops [10, 11]. In particular, specific image processing techniques will allow mapping and estimating biophysical variables such as leaf chlorophyll content and leaf water content, indicators of crop health, and the Leaf Area Index (LFA), an indicator of crop development. Remote sensing data together with ML algorithms will be used to predict crop yield. Recent works have shown that this combination can accurately estimate harvesting time [17, 18].

ML algorithms make predictions from analysing data sets. In order to have robust and reliable forecasts, large data sets of the past years are needed: these are used to *train* the algorithms. To this aim, we will exploit the open access data from Landsat 7 and 8 (USGS/NASA) and Sentinel-1 and 2 (ESA). Since weather, growth, and management practices alter crop yield, accurate *predictions* will be made from satellite data with good geographical coverage, short revisit time and high spatial resolution - such as the data from Sentinel-2 (A and B).

After determining crop type, predicting harvest time and quantity available, *agricultural waste* will be *estimated* following existing empirical models that correlate the ratio between crop yield and crop residue [10].

2.2 Description of the online platform

We envision the development of the platform in two stages. In the first stage, the platform would be an information database: the aim would be to increase the uptake of agricultural waste processes. By typing the location of your business or location of interest, the platform will search and list nearby farms. The output information available will include: crop type, anticipated time of harvest, available crop residue (quantity), and distance. In the second stage, we want to develop the platform further to allow farmers to directly sell their waste to biochemical companies: a marketplace for agricultural waste in Europe. The platform would then include information on the price at which the waste is sold and the estimated price when collection and transportation is included.

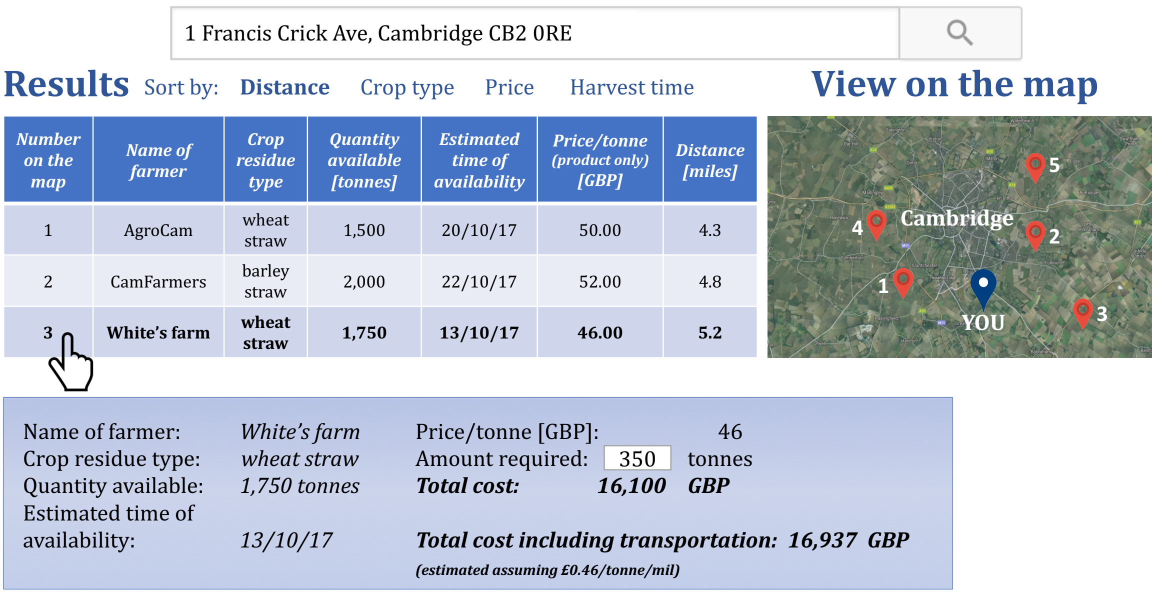

Fig. 2: Online platform mock-up screenshot at stage two of development.

Fig. 2 shows a screenshot of the platform at its second stage of development. As an example, let's assume that *AstraZeneca*, headquartered in 1 Francis Crick Ave, Cambridge CB2 0RE, UK, want to buy 350 tonnes of wheat straw for producing biochemicals. They access the platform, insert the location in the search bar, and a list of farmers with the corresponding location on the map will appear. The crop residue is required to be delivered to the company by 18th October 2017 in order to start research on a new pharmaceutical drug. Considering the crop type, price/tonne and availability, *AstraZeneca* select

White's farm. On the next step, a new window showing the details of the farmer would appear. *AstraZeneca* insert the amount of wheat straw needed, i.e. 350 tonnes, allowing them to envisage the total cost, including the estimated cost for transportation, and they proceed to make the order. The farmer *White's farm* will then receive and process the order. Note that in this example the values for the price per tonne of straw used were the ones of May 2017 [19] and that the cost for transportation was assumed to be £0.46/tonne/mile (average value for $<$ 10-mile journeys in the UK) [20].

3 Benefits

The outcomes of the proposed online platform have been identified using a PESTEL analysis. The framework highlights the political, economic, social, technical, environmental and legal aspects for various stakeholders. A summary is shown in Fig. 3, and described in detail below.

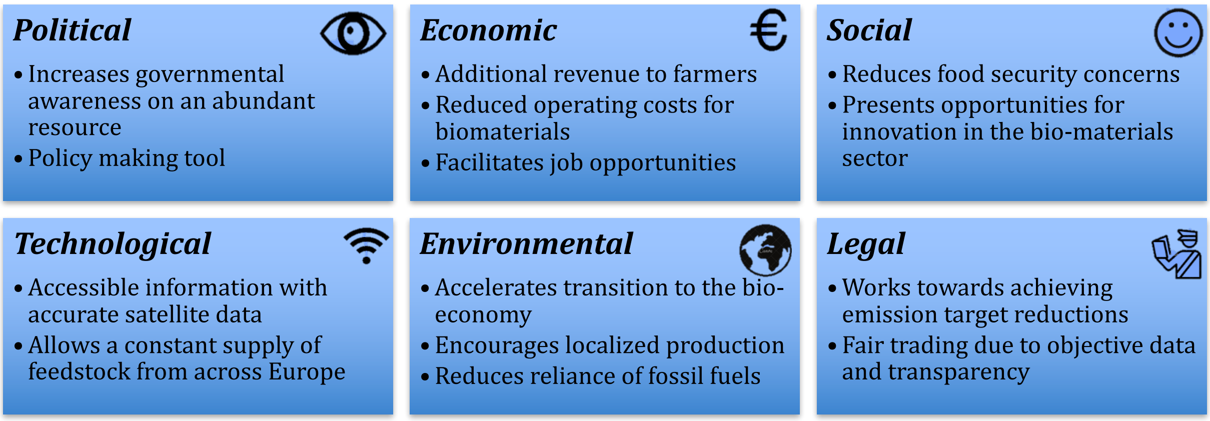

Fig. 3: PESTEL analysis identifying key benefits of project.

Having a clear picture of agricultural waste across Europe would not only benefit the private sector but also the public sector. Governments may use the database as a policy-making tool. For example, if a country has a significant proportion of crop residues, having quantifiable data would allow governments to build a case for change and set new policies to accelerate the transition to the bioeconomy.

The tool would facilitate sustainable economic opportunities across Europe. Research has suggested that fully exploiting agricultural waste may lead to revenue of €15 bn for the rural economy [21]. Furthermore, job creation opportunities from biorefineries and agricultural harvesting may be up to 300,000 by 2030 [21]. Additionally, using waste as a resource will significantly reduce manufacturers feedstock costs in comparison to utilising virgin material.

From a social perspective, the tool improves farmers' welfare as they have the opportunity to make additional revenue from their agricultural waste. Typically, farmers leave this waste to disintegrate into the soil or sell the straw bales as animal bedding [22]. In some European countries, farmers illegally burn their agricultural waste causing severe air pollution [23]. The tool would eliminate this problem by adding value to a typically wasted resource. Moreover, informing the public of the availability of abundant resources would stimulate innovation in the biochemicals sector.

In regards to technological benefits, satellite data enables agricultural land to be analysed across several thousand square kilometers at high processing speed. The process is far more efficient than manually contacting farmers and making crop residue estimates. Another advantage is the ability to connect businesses with a constant supply stream of agricultural waste. Currently, local procurement of agricultural waste is dependant on the harvest season; this is a major drawback to utilising waste at a large scale or where a constant supply is required. The platform would allow businesses to identify and plan feedstock availability throughout the year, across Europe, thus overcoming possible localised problems that farmers may encounter (e.g. reduced yield, storms, pests, droughts).

Sustainable production should ideally be localised, manufacturers should take advantage of regional materials to minimise transportation costs and carbon dioxide emissions associated with them. However, companies often are unaware of local materials due to a lack of available information. Utilizing satellite data on a global scale enables a clear picture of resource availability at local scale. For example, a biochemicals company may discover their required feedstock is produced at a farm only a few kilometers away.

Moreover, increasing activity in the bioeconomy sector may accelerate countries ability to meet the EU 2020 climate change agreements (20% reduction in greenhouse gas emissions and 20% of EU energy from renewables) [24]. From a legal standpoint, future versions of the platform that feature a marketplace would enable fair and responsible trading due to the use of objective data and transparency.

4 Feasibility

The feasibility of the project has been assessed using a SWOT analysis, briefly summarized in Fig. 4.

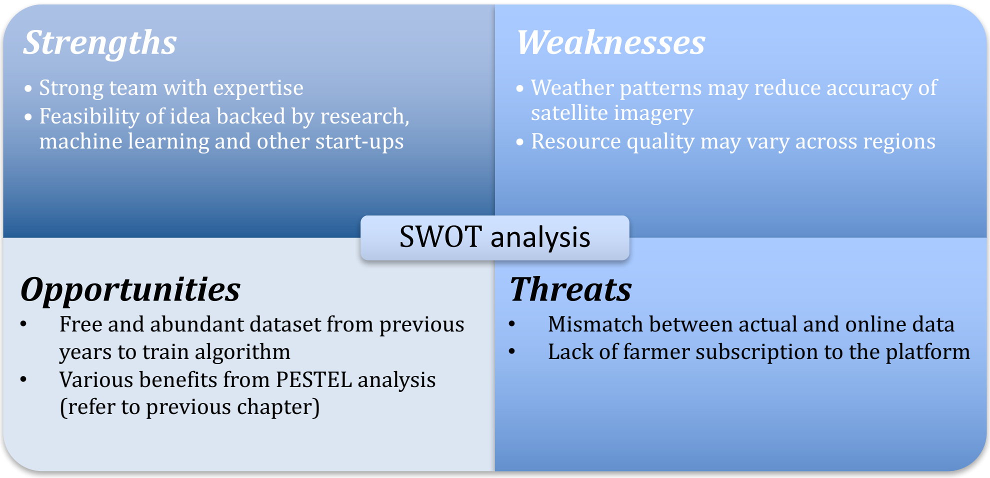

Fig. 4: SWOT analysis identifying project risks and feasibility of implementation.

In terms of strengths, the project team has expertise in multi-disciplinary backgrounds (including chemical engineering, sustainable development, aerospace engineering and applied mathematics) that will help shape and compliment the skills required to implement the proposed project. Furthermore, in terms of technical viability, remote sensing for precision farming is a proven technology [10, 11].

The project exploits abundant and freely accessible satellite data online. As a result, it would be feasible to create strong and robust algorithms that have analysed years of data. Other drivers that increase the feasibility of implementing the project are discussed in the PESTEL analysis of the benefits section.

However, reliance on satellite data exposes potential accuracy risks. For example, weather patterns may obscure or disrupt data, leading to inaccurate predictions of harvest time. To address this weakness, data from Sentinel-2(A and B) may be integrated with data from other satellite constellations (e.g. Earth-i, AgSpace, Planets).

Potential threats to the project include discrepancies between actual data and calculated data. To overcome such threat, the ML algorithms need to be trained with very large data sets. Moreover, verified farmers may provide actual data to include in the computations to improve the accuracy of the predictions. Another threat is the potential lack of farmer and industry subscription to the platform; this may be prevented through sufficient campaigning, advertising and government subsidies to incentivise usage of the platform. A final consideration is that once a manufacturer is connected to their resource, the logistics involved in transporting the waste to the site may be complex. During the initial launch of the platform, it will be anticipated that a third party will manage transportation of crop residues to site. However, as the platform develops, future versions will include an integrated transportation service.

5 Conclusions

The transition to the bioeconomy is a necessary step towards a more sustainable world. From an economic perspective, its market size, which is currently worth \$61-93 bn, is rapidly growing and it is expected to reach $174-225 bn in the next decade [25]. For the transition to happen, land must be dedicated to growing crops as feedstock for biochemicals. However, as the cultivable land is finite, one should either exploit part of the land currently used for food or “create” new land. The issue concerning the former is that it may impact local food security, while the latter may involve, for instance, deforestation, converting urban landing into agricultural land, and larger water consumption. Agricultural waste provides a valid and attractive alternative as no extra resources are needed. In Europe, over 139 million tonnes of agricultural crop residues are currently sustainably available for removal and utilization [4, 5].

In order to exploit this currently untapped resource, we propose an online platform, both website and mobile application, that uses a combination of satellite imagery, multispectral instruments data and machine learning techniques to provide a quantitative geolocalised measure of the agricultural waste in Europe. Remote sensing data will come from Sentinel-2 for future predictions and, to train the algorithms, free data from Landsat 7 and 8 and Sentinel-1 will also be used. The online platform would initially consist in an information database that will connect biobased companies to farmers. Subsequently, the platform will become a marketplace where companies will be able to buy residues from farmers.

Thanks to the abundance of data from future flocks of nano and micro satellites, UAVs, and satellites we envisage our platform to improve its robustness and accuracy as even more sophisticated models might be included, e.g. weather forecasts. In conclusion, our solution successfully encapsulates the benefits of satellites to drive sustainable development in Europe.

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