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Circular Bioeconomy in Action: Collection and Recycling of Domestic Used Cooking Oil through a Social, Reverse Logistics System

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Abstract: The inappropriate disposal of millions of tons of domestically produced used cooking oil (UCO), either down domestic household drains or in landfill, causes significant detrimental effects on the environment but also constitutes the loss of a valuable resource, since used cooking oil is a sought-after feedstock for biodiesel production. This paper presents findings from a social reverse logistics system, called InnovOleum, for collecting and recycling domestic used cooking oil through schools. The disruptive, social aspect of InnovOleum derives from the provision of funds from the sale of the collected used cooking oil to be invested within the participating schools in ongoing environmental education and green infrastructure and technology. To date, over 200,000 Euros have been distributed to schools for this purpose. No other schemes with similar potential to fully harness the environmental and social benefits from the collection and conversion of domestically produced used cooking oil have been found in literature. This publication can therefore significantly contribute to the knowledge base and facilitate the transfer of this scheme elsewhere.

Keywords: biofuel; bioeconomy; environment; recycling

1. Introduction

Used cooking oil (UCO), or waste cooking oil as it is also called, is edible oil of vegetable or animal origin that has been used to cook food to a point where it is no longer fit for that purpose. There are two main sources of UCO: Commercial UCO from hotels, restaurants and caterers (HORECA) and domestic UCO (dUCO) from households. Accurate estimates of global UCO production are not available, due to lack of reporting and the great difficulties associated with estimating UCO production from oil consumption patterns. It is, however, estimated that at least 16.54 million tons (Mt) of UCO are produced every year among the largest producing countries and regions, i.e., China, Malaysia, the United States of America, Europe, Taiwan, Canada, and Japan [1]. In Europe, recent estimates suggest that 1.66 Mt of UCO are available, 0.854 Mt from the household sector and 0.806 Mt from the commercial sector [2].

Commercial UCO has been actively collected in many European countries for the past 30 years, initially to serve the needs of the animal feed market. However, an EU-wide ban in 2002 on using UCO as animal feed in the form of the Animal By-Products Regulations [3], in response to the need to prevent the spread of exotic diseases such as foot and mouth disease and transmissible spongiform encephalopathies, led to UCO collectors having to identify new customers for their service. Around the same time, an expansion in the biofuel industry, which led to an increased demand for feedstock, provided the required new market.

In 2009, two European Directives, the Renewable Energy Directive [4] and the Fuel Quality Directive [5], aiming to promote the use of renewable sources of energy came into effect, providing further support for the sector's growth. The Renewable Energy Directive set a 10% target for the use of renewable energy in road transport fuel by 2020, so as to 'provide certainty for investors and encourage continuous development of technologies which generate energy from all types of renewable sources'. However, concerns about the effects that these EU goals, and other international measures, had on the take-up of arable land for the production of energy crops resulted in the adoption of the Indirect Land-Use Change (ILUC) Directive in 2015 [6]. According to the ILUC Directive, which aims to reduce the risk of indirect land use changes and promote renewable energy generation from advanced biofuels, the share of biofuels from crops grown on agricultural land that can be counted towards the 2020 renewable energy targets is set at 7%, whereas some alternative feedstocks, including used cooking oil, can be counted twice towards the 2020 target of 10% for renewable energy in transport.

These developments caused a rapid growth in the UCO market, whereby from around 2010 onwards, UCO producers, who up to that point had paid to have their UCO collected, had a valuable resource on their hands. Now, collectors have to pay to obtain the UCO. The capacity of the biodiesel market is now so large in Europe that the UCO collected domestically is not enough, and UCO is regularly imported from third countries [7].

According to the European Biodiesel Board [8], the EU biodiesel industry, which includes the production of biodiesel from UCO, currently produces 11.6 million tons of biodiesel, whereas the capacity of the UCO refinery sector is over 21 million tons. Specifically regarding biodiesel from UCO, known as UCOME, there was an estimated 30% gap between supply and demand in 2018, with Europe needing to import approximately 500,000 tons of UCO [9]. At least part of the gap between supply and demand could be closed through the collection and conversion of domestic UCO.

Domestic UCO is a relatively untapped market, mainly due to the logistics involved in collecting small amounts of UCO from a very large number of individual households. Out of the estimated 854,000 tons of domestic UCO produced in Europe, only about 48,000 tons are collected (5.6%), with collection being quite fragmented [2]. According to the same source, just three member states, namely Belgium, Austria, and the Netherlands, have managed to collect a significant portion of their domestic UCO through well-established countrywide collection systems, whereas in the remaining EU countries, efforts to collect domestic UCO are fragmented, if at all available. In fact, in most European countries, 0%, i.e. none of dUCO is collected.

Consequently, nearly 800,000 tons of UCO are inappropriately disposed of and end up in the environment, either through direct disposal in drains or through bottling and disposal in landfill. When released in water, oil increases the chemical oxygen demand with detrimental effects to marine organisms [10]. Additionally, UCO that is disposed of down drains costs millions of Euros to water boards, as the separation of oil from water is 700 times more expensive than regular water purification [2]. Furthermore, clogs of pipes from solidified fats and oils are a common phenomenon, and reportedly cost Thames Water, the UK's largest water and wastewater service provider, 1 million GBP per month to clear [11].

On the other hand, the greenhouse gas emissions from the production and consumption of biodiesel from UCO are between 60% and 93% lower than the emissions from conventional diesel [12–14]. Additionally, research has shown that domestic used cooking oil produces biodiesel with a higher yield than UCO from HORECA [15]. There are, therefore, significant environmental and economic reasons for diverting domestic UCO from inappropriate disposal into the circular economy where it can be used to produce biodiesel, thus facilitating the transition to a circular bioeconomy.

The bioeconomy 'encompasses the production of renewable biological resources and the conversion of these resources and waste streams into value added products such as food, feed, bio-based products and bioenergy' [16]. The utilization of organic waste materials for the production of energy is considered as one of the most sustainable options for energy production, as it transcends the conundrum of reconciling the needs of agriculture and industry, minimizing energy production's interference with food production, and thus leading to lower greenhouse gas emissions [17].

To maximize the positive effects of the UCO bioeconomy, domestic used cooking oil collection and conversion must be facilitated.

This paper presents findings from a social reverse logistics system, called InnovOleum, for collecting and recycling domestic UCO through schools. Rogers and Tibben-Lembke [18] provided the most widely used definition of reverse logistics, as 'the process of planning, implementing, and controlling the efficient, cost effective flow of raw materials, in-process inventory, finished goods and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal'. Reverse logistics systems can be implemented proactively, e.g., for cost savings, competitive advantage or environmental performance reasons, or reactively, e.g., in response to legislative requirements [19]. Regardless of the motivation for their implementation, a commonly cited drawback of reverse logistics systems is that, although they address financial and environmental parameters, social parameters are often neglected [19–21]. The reverse logistic system implemented as part of InnovOleum addresses the triple bottom line, bringing about financial, environmental, and social benefits. The main social aspect of InnovOleum derives from the return of funds from the sale of the collected UCO to schools to be invested in ongoing environmental education and green infrastructure and technology within the participating schools.

2. Method

2.1. Setting Up InnovOleum in Cyprus

InnovOleum began as a pilot in five schools in the Aglantzia area of the capital of Cyprus, Nicosia, in the school year 2012–2013. As schools in Cyprus are run by the central government, the project received all the necessary permissions and was launched in collaboration with the Pedagogic Institute of the Cypriot Ministry of Education and Culture. Targeted schools received an invitation by the Pedagogic Institute to join the program, which was named 'Tiganokinisi' (loosely meaning 'frying pan movement' in Greek). Following the success of the pilot phase, the project was expanded to include all the schools of Nicosia in the school year 2013–2014. From the school year 2014–2015, the program was opened up to all the schools in Cyprus. Today, InnovOleum includes over 85% of Cypriot schools.

The novelty of InnovOleum is the close link between environmental education and the provision of funds to schools through the sale of the collected UCO. At the end of the school year, each school receives an amount equivalent to approximately 500–600 Euros for each ton of UCO collected at that school, to be invested in green infrastructure and technology, with a view to furthering environmental education and promoting technological innovation. This innovation is coupled with the creation of jobs for unemployed university graduates, who undertake the educational activities.

InnovOleum is implemented as follows:

1. Oil collection drum installation: Interested schools contact the program and an oil collection drum is installed at the school, in a suitable, accessible, and secure location. Each school then defines a day of the week when students take UCO placed in bottles from home and deposit it in the drum. Once the drum is almost full, the school contacts the program, a driver is dispatched to the school, and the oil is collected, using a van equipped with pumps and tanks that are used to load the bulk oil and transport it to a management facility.
2. Community involvement: Schools are encouraged to involve their local community in the program in several ways, including (a) the provision of information to the general public about the program and encouraging the entire community to donate their dUCO; (b) involving local businesses (HORECA) to donate at least part of their UCO to their neighborhood's school, especially if a family member is attending that school; and (c) collaborating with the local authority to facilitate dUCO collection from less accessible households.
3. Educational presentations: Participating schools are visited by the InnovOleum mobile information and education center that is operated by a team of young, unemployed graduates (educators, scientists, engineers, etc.). The mobile education center visits participating schools

and, through several experimental setups, delivers age-appropriate, interactive presentations on (i) the entire process of the transformation of UCO into biodiesel, (ii) water- and energy-saving measures, and (iii) organic waste management, especially composting. Students participate in the implementation of the experiments, and this provides them with hands-on, experiential education on sustainability and its link to sciences and technology.

4. Digital platform: Schools have access to a digital platform through which they can identify and purchase sustainable 'green' technologies that they can implement at the school using the funds received from InnovOleum.
5. Experiential education: An educational guide is available, allowing teachers to use the program as an educational tool in their classroom, e.g., in mathematics, sciences, or languages. The guide is continuously updated to include any new technologies/infrastructure installed at the schools and provides details on how to incorporate them to become an essential part of teaching, allowing students to observe phenomena and understand the governing principles. In this manner, the entire school infrastructure can become part of the educational environment, facilitating experiential education for the students and promoting education in sciences, technology, engineering, and mathematics (STEM).

2.2. Selection of Schools

Schools are encouraged to participate in the program through official circulars issued by the Pedagogic Institute of Cyprus at the beginning of each school year. The circulars are communicated to each public school and include information about the scope of the program, the benefits to students and schools, and several administrative details regarding registration to the program and initiating the process of oil collection. The involvement of schools in InnovOleum is therefore voluntary and interrelated to the willingness of the schools' management to take action for the implementation of the program.

2.3. Stakeholder Participation

The successful participation of schools in the program is primarily based on the collaboration of teachers, students, and parents. Teachers are the driving force that encourages students to bring UCO from their homes; students are then engaging their parents in the process of collecting UCO at home. Schools are also encouraged to enhance their collection of UCO by working together with their local community, i.e., local businesses and local authorities. To do so, students themselves act as promoters of the program undertaking informational activities, or merely asking owners of local businesses to donate part or all of their UCO to the school. InnovOleum educators provide support to this synergistic approach by offering training to teachers and students and implementing awareness raising presentations to the local community and informing parents through targeted promotional material.

2.4. Data Collection, Analysis, and Interpretation

Throughout each school year, InnovOleum's team records and registers the amount of UCO collected by each school and associated collection points (i.e., HORECA businesses). By the end of the school year, the number of participating schools and businesses is tallied, and the cumulative quantities of UCO and corresponding funds for each school are calculated. Final results are double-checked by the Pedagogical Institute and are announced to schools through an official circular. By the beginning of the next academic year, schools receive the funds that they accumulated through InnovOleum in the past year. They then provide a short report to the Pedagogic Institute about how they invest the money, linking the actions they implement to the 17 Sustainable Development Goals [22]. Data on the number of participating schools and businesses, on the amount of collected UCO and on the amount of money returned to schools undergo simple statistical analysis that allows the observation of trends. Information provided by schools on the investment of the received funds is analyzed so as to allow the categorization of the practices into four main groups: 'Greening of schools', 'Infrastructure and Technologies', 'Awareness Raising', and 'Educational Material'.

3. Results

Within the first four years of InnovOleum's nationwide implementation in Cyprus, there was a steady increase in the number of participating schools, reaching 376 schools, approximately 85% of schools in Cyprus, in the 2017–2018 academic year (Table 1, Figure 1). This growth has taken place organically, with relatively little publicity, as a result of the positive experience of participating schools.

Table 1. Evolution of InnovOleum's implementation in Cyprus.

School Year	No. Participating Schools	UCO from Schools (kg)	No. Active Businesses	UCO from Businesses (kg)	Total UCO Collected (kg)	Funds to Schools (€)
2014–2015	282	59,885	63	11,726	71,611	37,161
2015–2016	312	66,296	65	14,565	80,861	50,836
2016–2017	310	71,105	59	16,507	87,612	53,761
2017–2018	376	88,933	95	24,933	113,866	66,249

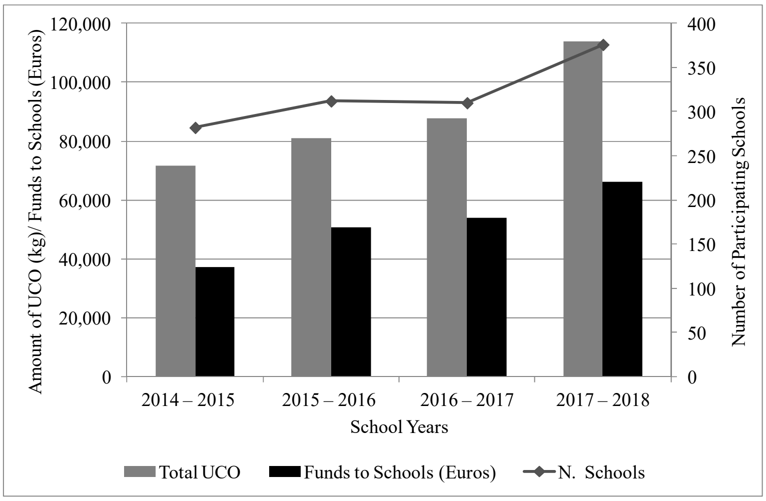

Figure 1. Number of participating schools, used cooking oil (UCO) collected, and funds received by schools from 2014 to 2018.

In the school year 2017–2018, a total of 75,457 students became involved in InnovOleum through their school's participation, with the average amount of UCO collected per student amounting to 1.5 kg. Importantly, some schools achieved much greater UCO/student ratios by taking more proactive action. For example, in one particular school, 68.1 kg/student were collected. This was achieved by raising awareness in the local community about the environmental effects of inappropriate disposal of UCO, the benefits that its collection through InnovOleum has on the school community and the students, and by encouraging small and larger businesses within the community to donate their UCO.

Engagement of the local community resulted in the increase of the number of businesses actively donating UCO to schools. The 2017–2018 academic year marked the peak of business involvement, with 95 businesses contributing nearly 25 tons of UCO to InnovOleum, accounting for approximately 22% of the total collected UCO (Figure 2).

Depending on the market price of UCO produced biodiesel (UCOME) and, thus, the purchase price of UCO by converters, the funds provided to schools at the end of each school year range from approximately 520 to 630 Euros per collected ton of UCO. Schools are able to spend this money on a variety of products that improve the sustainability of the school unit, contribute to continuous environmental education at the school, and/or raise environmental awareness within the school community and the wider community.

Since 2014, schools have received 208,007 Euros, which have been invested in the 'Greening of schools' (45% of all distributed funds), in the purchase and installation of green 'Infrastructure and Technologies' (41% of all distributed funds), on 'Awareness Raising' activities (11%), or in the purchase of 'Educational Material' (3%) (Figure 3). The category 'Greening of schools' includes the purchase of all the necessary materials for the creation and maintenance of botanical and herb gardens within the school as well as the purchase of materials for the creation of shaded areas within the school, using primarily trees and sheds made of sustainable materials. In all cases, this was closely linked to the classes of geography and/or biology, as students were responsible for investigating the type of plants/herbs that are most suited to the Cypriot climate, preparing the ground, and cultivating and harvesting the plants. The category 'Infrastructure and Technologies' includes the purchase of recycling bins, composters/shredders, solar water heaters, hand driers, LED lights, water saving equipment, solar ovens, and other similar equipment. The purchase of environmentally related books, model wind turbines, solar vehicles, etc. to be included in the day-to-day classes of the students is what is included in the 'Educational Material' category, whereas the category 'Awareness raising' includes a host of activities ranging from the preparation informational signs placed within the school and at key points within the community, to the purchase and distribution of reusable containers for the transfer of food and drinks by students to school, to key interventions within the community, such as participation at environmentally-related events to promote InnovOleum, cleanups of riverbeds, sidewalks, etc.

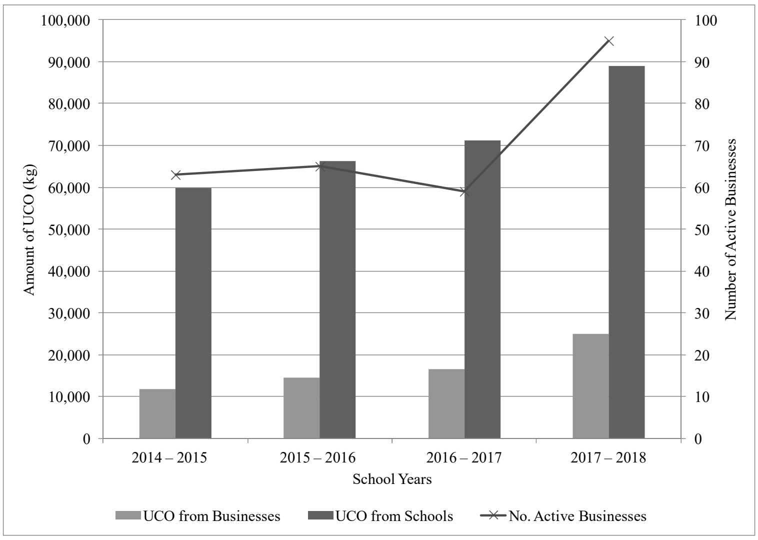

Figure 2. Businesses donations of UCO between 2014 and 2018.

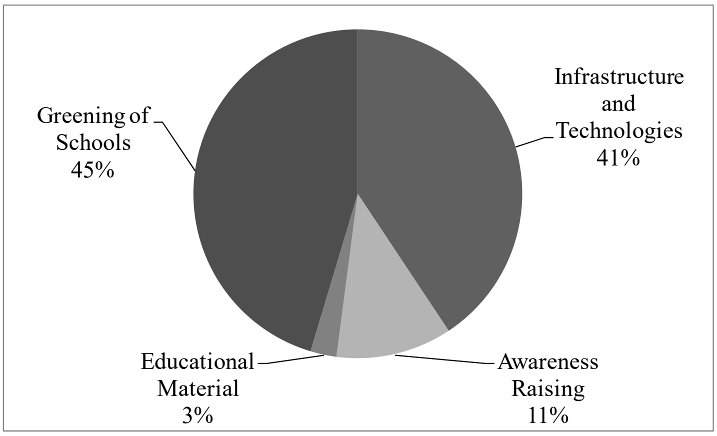

Figure 3. Modes of investment of InnovOleum funds by schools.

4. Discussion

Literature on domestic UCO collection is scarce, as the majority of research work is focused on the technical and technological aspects of UCO to UCOME conversion. One relevant study compared three different dUCO collection systems—door-to-door, through centralized collection centers and collections from specific locations, including schools and sports clubs—and found that from an environmental sustainability perspective, collecting dUCO at urban collection centers is more sustainable, especially if other waste streams are also collected from these centers [23]. However, from a social perspective, door-to-door collections and collections through schools are more sustainable. In fact, recent pilot studies to collect dUCO from schools have shown that interest is great and if sustained, schools can successfully become collection hubs for dUCO [24]. However, none of these pilot systems have managed to maximize the social and environmental benefit associated with utilizing schools as the starting point of the reverse logistics chain, as their application remained at the pilot stage, not having yet managed to overcome the bottlenecks associated with dUCO collection.

As InnovOleum is still in its infancy, its long-term impact remains to be determined, although its potential to positively affect the environment and society, at various levels, is evident (Figure 4), as InnovOleum meets a series of social and educational needs:

- It helps to transform school infrastructure through the provision of funds for making schools 'greener' and helps further traditional and experiential education at schools. This helps to meet the United Nations Sustainable Development Goal number 4 'Quality Education', as it promotes inclusive and quality education as well as lifelong learning, through the involvement of the community [22].
- School children and youth actively participate in the process, and this creates a sense of ownership and the feeling of co-responsibility for the 'greening' activities that are implemented.
- The implementation of practical solutions to real environmental and social problems allows children, youth, and the society to become a part of the circular economy and contribute to the fight against climate change, thus helping to meet Sustainable Development Goal 13, to take urgent action to combat climate change and its impact.
- Through the integration of the InnovOleum educational material, developed to take into consideration green technologies and infrastructure, into the academic curriculum, sciences, technology, engineering, and mathematics (STEM) are promoted among students. This is particularly important in countries such as Cyprus, where interest of youth in STEM is the lowest in Europe [25].
- The presence of young, female scientists as InnovOleum's environmental educators/trainers further adds to the promotion of STEM among young women.
- By employing unemployed young scientists as environmental educators/trainers, InnovOleum addresses an important European and global issue: Youth unemployment [22,26,27]. The young scientists are provided with skills development and capacity building on issues related to green economy and social entrepreneurship, thus increasing their employability.
- Local community actively participating in the UCO collection enhances the public commitment and support towards schools.

There are some inherent challenges to the implementation of InnovOleum, perhaps the most significant of which is the variable price of UCO. As UCO is traded on the international market, various factors, such as conventional fuel costs and new market openings, can affect its market value. Negative price fluctuations can decrease the 'profit' margin from the sale of the collected UCO, thus reducing the amount of funds that can be returned to schools. The ability to temporarily store the collected UCO until the market value increases and/or the establishment of an agreement with the UCO converting company for a standard price over the duration of the school year can 'buffer' against this challenge. The fact that the promotion of InnovOleum within the school is dependent on the

Principals and teachers is another challenge faced by InnovOleum, as it the need for route optimization (due to the large number of collection points) in order to minimize the logistics costs.

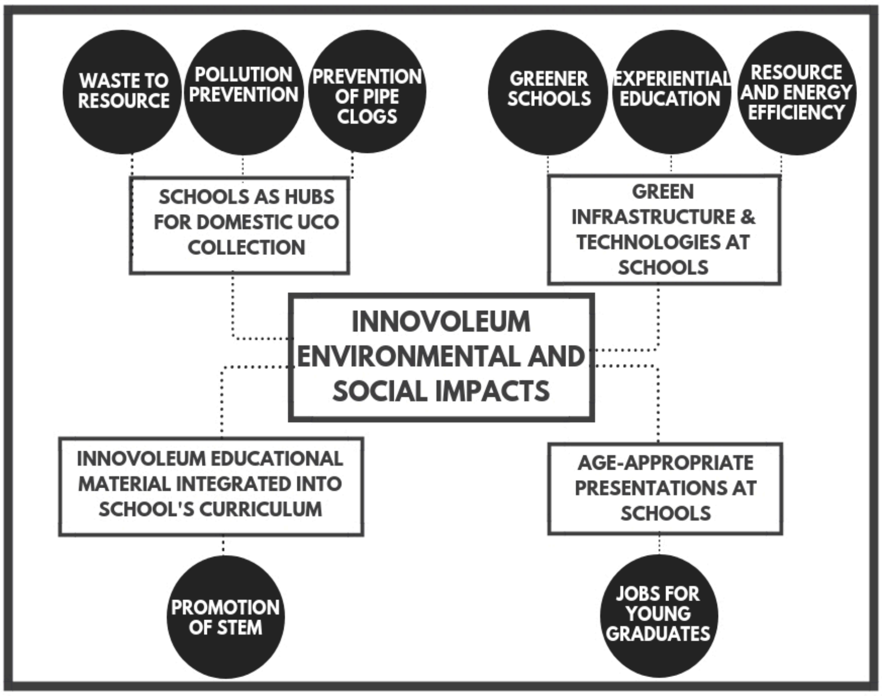

Figure 4. InnovOleum's environmental and social impacts.

Based on the results from the implementation in Cyprus, InnovOleum can contribute to the reduction of pollution resulting from the nearly 1 Mt of inappropriately disposed dUCO in Europe alone and the transition towards a circular bioeconomy. Europe is expected to remain the world's major producer of biodiesel [28,29], particularly with the upcoming revision of the Renewable Energy Directive, which will likely require that 14% of fuel used in transport comes from renewable sources and will place increasing emphasis on waste as the primary source [30]. This will sustain the continuous expansion of the UCOME market within Europe, further widening the gap between UCO demand and availability. InnovOleum can therefore be an important tool to assist European Member States in meeting the increasingly stringent renewable energy targets. However, the UCO market is expanding across the globe, particularly in Asia (especially China), the United States, and South America (especially Argentina and Brazil). In combination with policies and targets for renewable energy consumption and greenhouse gas reductions [4,5], the global UCO demand is therefore on the rise. This suggests that there is space for schemes such as InnovOleum across the globe.

5. Conclusions

Advanced and well-organized collection systems and education are the two most important factors for successful UCO collection from households [2]. InnovOleum meets both of these prerequisites and thus has the potential to become a best practice in dUCO collection. Through proper marketing and promotion and the continuous involvement of and engagement with the local community, InnovOleum can both sustain and maximize its environmental and social impacts, contributing to enhancing quality education, fostering environmental consciousness, creating job opportunities for youth, and combating climate change. The positive impacts and the potential for the internationalization of InnovOleum in Europe and abroad has been recognized through the award of the Horizon 2020 SME Instrument Phase 1 Grant to ISOTECH Ltd, for the development of a business model and feasibility study for the internationalization of InnovOleum. The outcome shows that a social franchise scheme could be used to transfer InnovOleum in other countries. Within this scheme, ISOTECH Ltd as the franchisor transfers know-how and experience to a nongovernmental organization which undertakes the role of master franchisee, responsible for the implementation of InnovOleum in its country. Unemployed youth undertake the role of unit franchisees, responsible for the environmental educations at schools and the collection of UCO.

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