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TECHNICAL AND ECONOMIC ANALYSIS OF USED COOKING OILS IN BIOENERGY SYSTEM: COMPARATIVE CASE STUDIES

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Introduction

The global energy demand is growing under the pressure of the current context of increasing food demand, diffusion of diets based on products with a high density of energy (livestock products, vegetable oils, sugar), globalization of food production and trade, growing intensity of agricultural practices, competition on land use, exacerbation of global warming, and environmental concerns [Zhang and Chang, 2009; EIA, 2016, Soytas et. al, 2007; ICPP, 2001, Lutz et al. 2012; Lund, 2007; Saidi and Hammami, 2015; Sen and Ganguly, 2017; Nakata et al. 2011].

Renewable energy production represents a viable alternative for a transition from a petrol economy to bio-economy (IEA, 2010; Staffas; 2013) and more in particular for the mitigation of the environmental impact of fossil fuels (Cornelissen et al. 2012; Heidari, 2016).

The bio-economy can be defined as a system that provide energy, material and chemicals, and added value products by the sustainable use of biological resources (EuropaBio, 2011; European Commission, 2012, Socaciu, 2014). The bio-economy, can also offer competitive and innovative opportunities for more inclusive economic growth, jobs creation, and rural development in accordance with population growth and a sustainable management of natural resources (Lehtonen and Okkonen, 2013).

A key sector of the bio-economy is bioenergy where the agricultural systems became an energy supplier providing biomass feedstock such as dedicated energy crops, perennial grasses, short rotation forestry, non-food cellulosic and ligno-cellulosic biomass (Tilman et al. 2006; Campen et al. 2010; Cherubini, 2010; Johnson and Altman, 2014).

The potential role of bioenergy systems has been recognized by national governments and international organizations through its introduction in strategical documents and the provision of dedicated subsidies.

At the European level the rural development policy was introduced as the second pillar of the Common Agricultural Policy during the Agenda 2000 reform (EU, 1997) and one of the items supported by the rural development policy as has been the production and use of renewable energy (EU, 2008).

In the United States, within the Farm Bill, the Energy title was added in 2002. Since then, USDA renewable energy programs have been used to incentivize research, development, and adoption of renewable energy projects, including solar, wind, and anaerobic digesters. However, the primary focus of USDA renewable energy programs has been to promote the internal bio fuels production and use (USDD, 2002).

Although bio-energy represents a key element in climate mitigation strategies, its development is also leading to an increased pressure on land use and agricultural production (Rose et al. 2012; Popp et al. 2014).

Several critiques to the benefits of bioenergy production on land use change (Jacobs et al., 2016), GHG emission reduction, (Hudiburg et al. 2016) and food prices (Stevanovic et al., 2017) emerged, and the competition of food versus bioenergy become a hot topic in the international policy agenda (Wolf et al. 2003; WBGU, 2009; Hertel et al. 2010).

Sustainability assessment and new bioenergy targets on direct and indirect land use and GHG emissions saving have been included also in the European Renewable Energy Directive in 2009 and in the Energy Independence and Security Act in 2007 in the United States (Buchholdz et al. 2009).

Sustainable development calls for viable answers to address economic, social and environmental criteria (Meyar-Naimi, 2012) and real commitment to green management which may result in a positive influence on financial (Morina-Azorin, 2009) and environmental performances (Ting Tan, 2014), and on renewable energy goals and portfolio standards, for the possibility of meeting short and long-term objectives for renewable energy (Cucchiella et al. 2013).

In Italy, a more sustainable approach for biomass use was applied with the biogas production mostly from energy crops; by giving value to agricultural by-products such a new feedstock for biogas plants and with the short supply chain principle introduction for biomass availability (Italian Financial law, 2007). Agricultural residues are considered as a potential source for the energy system providing positive impacts on the entire agro-food sector. Furthermore, the use of local residual biomasses has allowed the stimulation of new value chains from neglected territorial resources and ensured income diversification opportunities for existing agro-industrial economies (Carrosio, 2014; De Menna et al. 2016).

Several studies have addressed the promising potential of residues from tomato (Bacenetti et al. 2015; Calabrò et al. 2015) potato (Schievano et al. 2009) olive oil extraction as skin pieces, pulp, stone, and kernel olive (Gianico et al. 2013) in the anaerobic digestion and co-digestion to valorize the energy from agro food system (De Menna, Malagnino et al. 2016) and to reduce the use of energy crops (Concha et al. 2017).

In United State sustainability standards were firstly integrated in the Renewable Fuel Standard Program under the Energy Independence and Security Act in 2007 requiring GHG emission reduction including all the GHG lifecycle, considering the indirect land use change. Moreover, advanced, biomass-based diesel and cellulosic biofuel categories were recognized for their higher contribution in GHG saving if compared with conventional biofuel based on energy crops use.

On the potential negative externalities energy crops for biogas production and biofuel could lead to deforestation, to direct and indirect land use change and have potential effect on the commodity market for food. Moreover, in terms of limitations, as other by products are affected by seasonality with yield fluctuation and uncertain availability.

The negative externalities of energy crops have been among the main reasons to focus the attention of this research on the potential use of used cooking oil (UCO) for bioenergy production. UCO is considered a kitchen waste, generated daily from agro-food industries, restaurants and homes and is characterized by a relatively high availability especially in urban areas.

Estimates suggest that UCO production is about 5kg per capita generated annually in the EU (Mangesh et al. 2006). Moreover, an average of around 4 Mh of UCO per person is produced annually in the US (Wiltsee, 1998; Zhang 2003) that can also been considered such a food waste loss by process (Kantor et al., 1997).

This research is motivated also because the improper management of UCO could lead to environmental pollution particularly on soil and water where UCO layer covers the surface and prevents the dissolution of oxygen (Jafari, 2010; Marjadi, 2010).

UCO can be used as input for energy use. In biodiesel production, in the US, the use of UCO is well recognized (Zang et al. 2003; Li et al. 2011) and defined by the EPA as the most environmentally friendly input for biodiesel since it is contributing to an 86% reduction in GHG emissions if compared to petro-diesel.

In the biogas sector, in the EU, although positive results have been proved for the use of UCO in co-digestion with swine manure (Fierro et al, 2014) and glycerol in co-digestion with pig manure (Nuchdang and Phalakornkulr, 2012; Li, 2011), the European regulatory framework still classifies UCO as a waste. In Italy such a classification limits the introduction of UCO in biogas plants.

Therefore used cooking oil can be considered either a waste product with negative effects on the environment or a resource in case of itss integration in bioenergy systems. The aims of this work have been to:

- assess the technical and economic feasibility of the substitution of energy crops with used cooking oil in anaerobic digestion;

- to analyze the effects of the substitution of energy crops with used cooking oil on land use;

to evaluate the feasibility of alternative policy interventions designed to enhance the UCO supply chain.

Chapter 1

Used Cooking Oils in the Biogas Chain: A Technical and Economic Assessment[1]

Abstract: The current concerns on global energy security, climate change, and environmental pollution represent some of the major elements of the growing interest on renewable energy. In this framework agro-food energy systems are at the center of a twofold debate: on the one hand they represent a key option for energy production while on the other their sustainability is threatened by the expansion of the bioenergy market that could lead to negative social and environmental consequences. The aim of this work is to evaluate—through a case study—the technical and economic feasibility of the replacement of energy crops (ECs) with used cooking oil (UCO) in an anaerobic digestion (AD) full-scale plant. At this purpose, a full-scale plant performing AD was monitored for two years. Three scenarios were developed and compared to evaluate the impacts and the potential benefits in terms of land saving in case of a substitution of ECs with UCO. Results highlighted a reduction of land use of over 50% if UCO is introduced in co-digestion with ECs. The lack of an appropriate legislative framework limits the utilization of used cooking oils (UCOs) in AD with a consequently missed opportunity for biogas owners that could find an important alternative in UCO.

Keywords: anaerobic digestion (AD); energy crops (ECs); used cooking oils (UCOs); land saving; waste management

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1. Introduction

The global energy demand is growing under the pressure of the current context of increasing food demand, diffusion of diets based on products with a high density of energy (livestock products, vegetable oils, sugar), globalization of food production and trade, growing intensity of agricultural practices, competition on land use, exacerbation of global warming, and environmental concerns [1–3].

These factors are leading national governments and the international community to increase the support and the investments to stimulate a reduction from the dependency on fossil fuels and a transition to a low-carbon society [4–6]. These commitments represent key elements for several international protocols, such as the Kyoto Protocol [7] and the European Climate-Energy Package "202020" [8,9], that aim at regulating emissions, cutting waste, and reducing the use of energy.

Agriculture represents a focus sector since it is, at the same time, an important energy consumer and bioenergy producer [10]. Dedicated crops and agricultural byproducts have been used to generate energy through thermo-chemical conversion processes, such as combustion, gasification, and pyrolysis [11], or bio-chemical conversion, such as fermentation and anaerobic digestion (AD) [12]. This work focuses on AD due to its rapid development in several EU (European Union) countries—including Italy—as a consequence of high renewable energy subsidies [13].

Along with the general recognition of the potential of biogas production, there is a growing debate on its sustainability due its impact on land use [14]. Land use change potentially leads to a variety of direct and indirect effects in agrarian systems. Direct effects include environmental degradation and the loss of biodiversity. Indirect effects comprise those related to economic changes as rising rents for land leases and growing commodity prices, and to social changes caused by the violation of land rights [15,16].

Within this context, the identification of solutions to ensure the sustainability of biogas production represents a crucial step to exploit the full potential of AD. An option is represented by the use of dedicated energy crops (ECs) associated with waste organic materials, by-products, and residues from agricultural and agro-industrial production [17] both in AD and in co-digestion processes.

Such practices could mitigate the environmental consequences of the production of ECs and increase the capacity of energy generation in rural areas.

Literature shows high energy efficiency values in the co-digestion of barley, molasses, industrial bakery products, and sludge crushers [18], pomace, tomato puree by-products [19], tomato skin, seeds and whey [20], artichokes [21], and fruit products, such as pineapple skin and pulp [22]. Additional by-products are derived from olive oil extraction as skin pieces, pulp, stone, and kernel olive [23].

As any agricultural product, by-products are also characterized by seasonality and yield fluctuations so that planning tools and supply analysis are particularly important [24].

As kitchen waste, used cooking oil (UCO) is not affected by seasonality or yield fluctuations as other by-products and is characterized by a relatively high availability: in Europe 5 kg per person corresponds to an overall potential of 2.5×10^6 Mg per year [25].

Before the entry into force of the European Commission Regulation 1774/2002 [26], which outlines the health rules concerning animal by-products not intended for human consumption, UCO was reused mainly as animal feed. With the introduction of this limitation, the attention on vegetable waste oils and its sub-products (glycerin and raw-biodiesel) increased significantly. Additionally, this attention was also raised by the potential profit opportunities generated by the exploitation of UCO [8,27] and the application of the Decree 152 of 3 April 2006 [28], which introduces the obligation for its collection.

The 22×10^6 Mg of biodiesel produced with vegetable oil in the EU-27 in 2011 stimulated the development of a number of projects aimed to improve UCO collection [29–32]. Additionally, several studies were carried out to assess its potential utilization in the biodiesel industry [33–35] and the valorization of its sludge by co-digestion with swine manure [36]. Positive results have been obtained also with the anaerobic digestion of glycerol and co-digestion of glycerol and pig manure underlying its versatility [37]. The

1.4 × 10^6 Mg produced annually in Italy are, in large part, collected and reused from C.O.N.O.E. (Italian National Consortium for Mandatory Collection and Processing of Waste Vegetable and Animal Oils and Fat) as vegetable waste oil [38]. Other uses are limited by the national and European regulatory framework that is currently prohibiting the use of UCO in the biogas sector.

The aim of this work is to assess the technical and economic feasibility of the substitution of energy crops with UCO in AD, with particular emphasis on the potential implications on land use.

2. Materials and Methods

2.1. Case Study Area

The case study area is represented by the Emilia-Romagna region, which is located in the southern part of the Pianura Padana and is characterized by a highly developed agricultural sector [39] where the introduction of the feed-in tariff at the beginning of 2009 stimulated a rapid diffusion of biogas with consequent implications on biomass availability and land rental rates [40].

Six of Emilia Romagna's biogas plants out of 24 are located in the municipality of Medicina that, for this reason, has been identified as the center of the study area.

The identification of the case study area was then based on the principle of short chain, which authorizes biomass-based biogas plants to procure within an area of 35 km [41] to facilitate the potential development of local energy districts. Such a mileage restriction allows significant benefits for reducing the emissions and the costs of biomass transportation.

Following this approach UCO is collected in a circle that has 50 km diameter, with Medicina at its center, and includes other 17 small municipalities plus the city of Bologna (Figure 1).

Figure 1. Case study area, 50 km diameter.

Five of the biogas plants of Medicina operate with a mix of agricultural by-products and dedicated energy crops, while the remaining one has a mixed feeding system that includes animal waste. The research was carried out in one of the plants operating with agricultural by-products and dedicated energy crops.

2.2. Data Gathering and Used Cooking Oil Collection

UCO quantification was based on a two-step methodology. Firstly, questionnaires were sent to A.R.P.A (Regional Agency for Prevention and the Environment) and C.O.N.O.E. to quantify the amount of UCO at local level (UCO is collected by the multi-utility H.E.R.A. (Energy Resource Environment Holdings), with the exception of the municipality of Castel Maggiore, where the collection is managed by Geovest Environmental Services.), identify the trends over time and collect market price data.

With the second step the information retrieved with the questionnaires were integrated and cross-checked with those available on the ISTAT (National Statistics Institute) databases.

2.3. Biogas Plant Description

The biogas installation analyzed in this study is located 8 km outside the town of Medicina. The plant has a potential power of 999 kW and started its operations in 2012 taking full advantage of the comprehensive tariff (incentive + electric energy produced) of

0.28 €/kWh that allows paying off the investment in a particularly short time (the legislative decree “Sviluppo” (Development) 1141 (approved on 1 July 2009) ensure a comprehensive tariff of 0.28 €/kWh for the plants entering into operation in 2012 and with a potential power of less than 1 MW). AD is a wet process with an average percentage of feed dry matter (DM) lower than 10%. It takes place in a mesophilic digester with a hydraulic retention time (HRT) ranging between 55 and 65 days, a temperature range of 44–47 °C, and a reuse of 30% of the energy produced by the combined heat and power (CHP).

The digester is composed of two reactors of 3000 m^3 each where the DM is mixed by stirrer blades. The CHP is based on an internal combustion engine modified by natural gas with an electric power of 1063 kW and an electrical efficiency of 40.1%. The volumetric load of about 37 $Mg \cdot day^{-1}$ of the total mass (wet basis) is charged without any pretreatment of the biomass.

2.4. Scenario Analysis

To analyze the substitution of ECs with UCO three different scenarios were developed: baseline (S1), intermediate (S2), and best case (S3).

2.4.1. Scenario S1: Baseline

The baseline scenario was developed along the real diet of the biogas plant for the 2013–2014 biennium. The daily load of each biomass $q_{x,i}$ [Mg] was averaged over a week to obtain the average daily load Q_x [Mg] where:

$$Q_x = \frac{\sum_{i=0}^{7} q_{x,i}}{7} \qquad (1)$$

The load was calculated in terms of corn silage equivalent tons (CSET) to allow a comparison among the energy potential of the different biomass utilized as feeding material and divided for simplicity into corn and byproducts.

CSET was calculated as the ratio between the biochemical methane potential of corn (BMP_c) assumed equal to 95 $Nm^3CH_4 \cdot Mg^{-1}$ wet basis (considering a 30% of volatile solids on the load) and the biochemical methane potential of each biomass used in co-digestion (BMP_x) multiplied for the load of each biomass Q_x [42–44]. The use of the BMP

[$Nm^3CH_4{\cdot}Mg^{-1}$] value as references allows the identification of the most appropriate feedstock to achieve the optimum biogas yield.

CSET was defined as:

$$\text{CSET [Mg]} = \frac{\text{BMP}_\text{c}}{\text{BMP}_\text{x}} Q_x \qquad (2)$$

A cumulative regression of the used corn was introduced to ensure a better data analysis. The 2013–2014 biennium has been divided in periods of four months to obtain six different trends, three per each year. The linear functions show the highest weekly energy corn consumption.

The amount of hectares needed to produce the quantity of corn required to feed the plant (*LU*) was calculated after the estimation of the total load plant diet per year (as average of the two years), in terms of corn ($C_{TOT,c}$) and biomass ($C_{TOT,b}$),:

$$LU\left[\frac{\text{ha}}{\text{year}}\right] = \frac{C_{TOT,c}}{AAY} \qquad (3)$$

where *AAY* $Mg{\cdot}ha^{-1}$ represents the corn average annual yield estimated in 55 $Mg{\cdot}ha^{-1}$. The same corn yield was also maintained for S2 and S3.

2.4.2. Scenario S2: Intermediate

The intermediate scenario (S2) builds on the dataset of the baseline scenario (S1) replacing corn with the real amount of UCO collected in the 2013–2014 biennium.

Corn was replaced with UCO when the corn quantity was exceeding the threshold value of 30 $Mg{\cdot}day^{-1}$ ($C_{TOT,c}$). The amount of *LU* needed to produce the requested quantity of corn was calculated using a new value of CSET assuming UCO's BMP as 10.21 times BMP_c [45].

2.4.3. Scenario S3: Best Case

The best case scenario (S3) assumes the potential collection of UCO in all the municipalities to be at the same rate of the one with the higher collected amount of UCO for 2013–2014 biennium. This new hypothetical quantity of UCO (QI_{UCO}) was calculated as the UCO per capita collected in the municipality with the higher UCO collection multiplied for the resident population of all of the municipalities. QI_{UCO} is supposed to be used to replace corn in the weeks with a total use over the fixed threshold.

Finally, the utilized land and the Mg day^{-1} of corn needed to feed the biogas plant were calculated utilizing the same methodology used in S2.

2.5. Revenue Account

The average market price of the UCO matrix during the 2013–2014 biennium was approximately €490 per Mg [38]. The price refers to the regenerated UCO utilized in different sectors.

The net present value (*NPV*) was estimated calculating the potential profit opportunities for the power contractor in a scenario where the entire amount of collected UCO is allocated to the production of energy. *NPV* was calculated as:

$$NPV = \sum_{t=0}^{\infty} \frac{R_t}{(1+i)^t} \tag{4}$$

where R_t are the inflow and outflow discounted back to the actual value and then added up.

The total cost (C_T) was valued as the sum of three different categories of costs/inflows: initial investment costs (C_i), management costs (C_G), and procurement costs (C_A). C_i is equivalent to 4 M based on a constant payment [46]; C_G represents an annual cost and depends on the amount of working hours corresponding to 8760 h·year^{-1} and an output of 999 kWh. Moreover, the energy produced has been paid as a management cost at a price of €0.03 per kWh. C_A represents the sum of the amount of each biomass used to feed the plant at its specific market price. Price changes depending on whether the biomass is purchased on the market or self-produced.

Revenues are calculated as the sale on the electricity market multiplied for the annual incentive before 2012, equivalent to €0.28 per kWh. Financial costs depend on the overall amount, on the interest rate (r) and on the mortgage term (q^n). The value of r is fixed and it is equal to 5%. The annual installment is calculated through the multiplier (k), which is defined as:

$$k = \frac{(rq^n)}{(q^n - 1)} \tag{5}$$

Within each scenario the specific NPV was calculated as the difference between the total revenue (R_T) and C_T. The annual money save (*MS*) was based on the difference between the NPV of the three different scenarios indicated respectively as NPV_{S1}, NPV_{S2}, and NPV_{S3}.

The profit opportunity (*PO*), that represents the potential market price that the UCO should have in a new energy chain, was estimated as:

$$PO = \frac{(NPV_{S2;S3} - NPV_{S1})}{QI_{UCO,c}} \tag{6}$$

3. Results and Discussion

3.1. Scenario S1: Baseline

The average composition of the feed-in matrices to be utilized in the digestion process is reported in Figure 2. Data are expressed in months, indicated as numbers (1, 2, 3, etc.), with each month composed of four periods (weeks) of seven days and the subsequent month starting at the end of the fourth period (i.e., Month 2_'13 is starting at day 29). Remaining days are included in months 13_'13 and 13_'14.

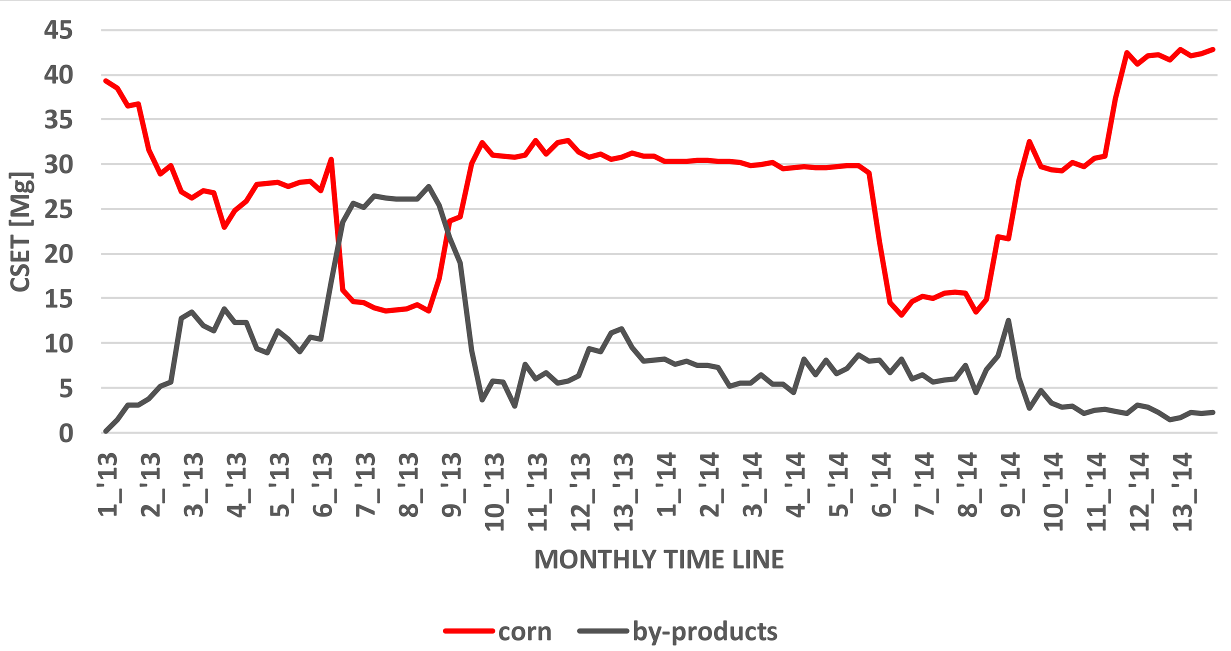

Figure 2. Monthly real biogas plant diet in the 2013–2014 biennium.

The total load is composed by corn (69.92%) and agricultural by-products (30.08%) with the generic term "by-products" including coffee beans, pomace, blueberries, flours, wheats, husk spelt, cocoa, and sorghum. By-products are characterized by a quite diversified mix and a relatively limited quantity of organic matter.

The diet includes also wheat that was not considered as an energy crop since it was originally produced for human consumption and was then reallocated to energy use only if it was degraded or affected by diseases.

Additionally, a reduction in the use of corn was registered between months 6 and 10 of the two years under analysis mainly due to the seasonality of the corn production cycle.

Considering corn yield per hectare the average annual land consumption was 182.20 ha·year^{-1} equal to 0.84 ha·day^{-1}.

Figure 3 highlights the surplus in the use of corn with the six series representing the periods of four months within the biennium under analysis.

R^2, the value of the coefficient of determination representing the average cumulative consumption of corn in the two years for all six series, is close to one, suggesting a good explanatory capacity of the model.

UCO was introduced in the weeks with a higher intensity in the use of ECs corresponding to the time series with a higher slope (3,4,6).

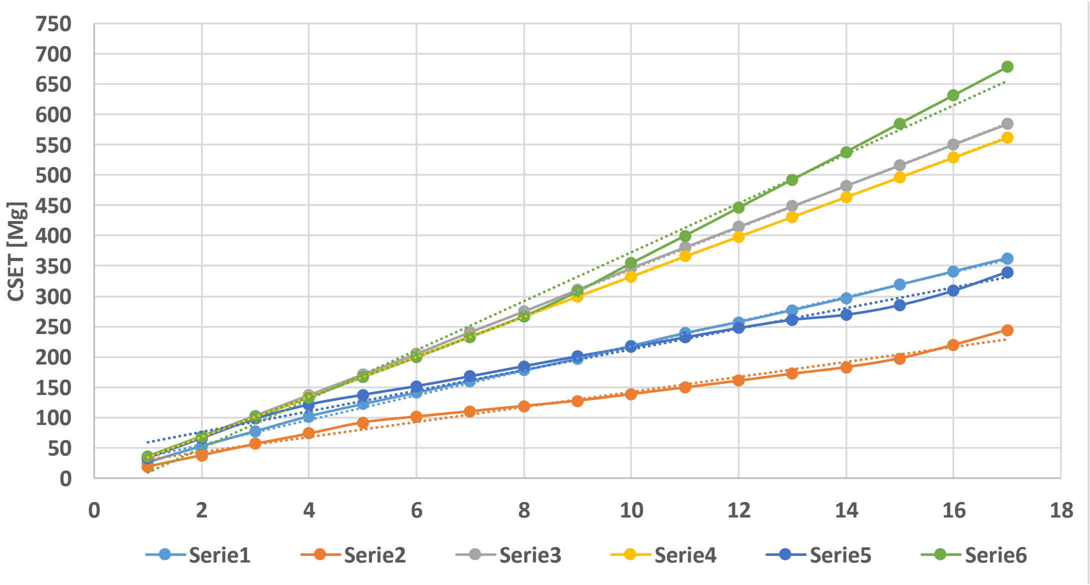

Figure 3. Cumulative distribution function of the corn used in the biennium 2013–2014.

3.2. Scenario S2: Intermediate

The average annual amount of UCO collected by authorized companies was approximately 146.28 Mg. Figure 4 shows the breakdown of the UCO collected in the selected municipalities. As predictable the municipality with the higher resident population (Bologna) presented the higher share of collected UCO.

The replacement of corn with UCO was assumed to ensure unaltered values for the total load, the electrical power, and the energy production.

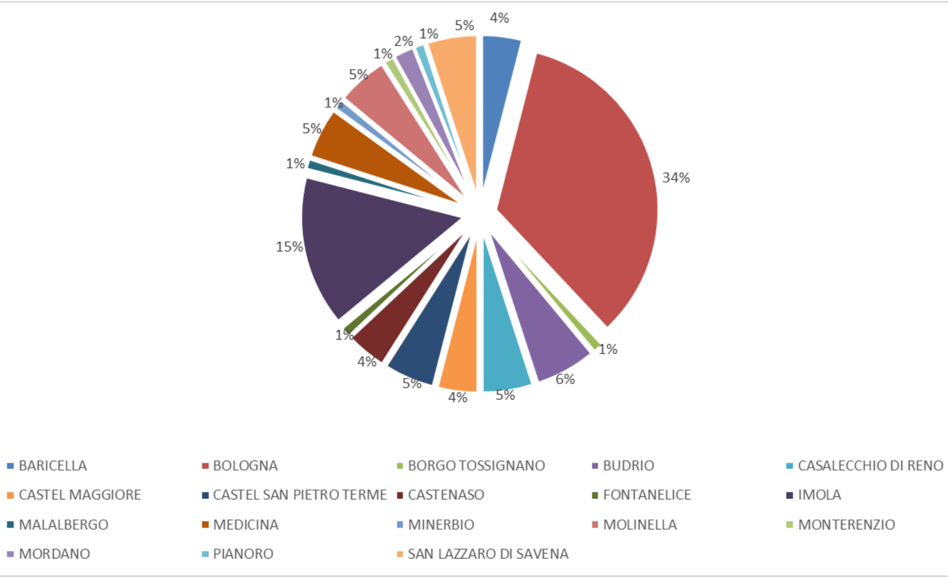

Figure 4. Used cooking oil (UCO) collected in the selected municipalities (as the percent of the total) in the 2013–2014 biennium.

During the 2013–2014 biennium, UCO has been introduced in all 46 weeks—out of 104—when the threshold value of 30 Mg·year^{-1} of corn was exceeded.

The 146.28 Mg of UCO were equally distributed along the 46 weeks for a weekly average of 3.18 Mg. The real plant diet has been reset for the new feedstock maintaining constant values for the production of electrical energy and for the total load. Figure 5 suggests that the introduction of this matrix ensured a reduction of the quantity of corn maintaining the same electrical system power.

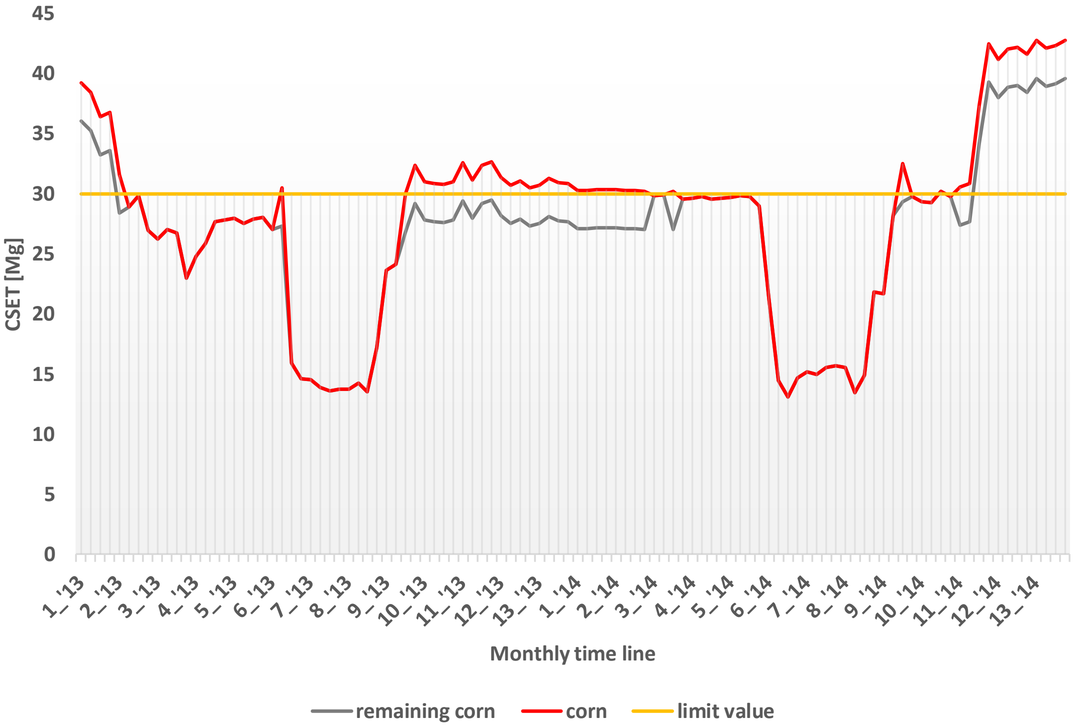

Figure 5. Corn required in the weeks that exceed the threshold value within S2.

In this scenario the overall amount of corn decreases of about 1480 Mg per year. This reduction corresponds to significant land savings: the corn area decreased from 182.20 ha in scenario S1 to 155.3 ha·year^{-1} in scenario S2 corresponding to the 14.8%.

3.3. Scenario S3: Best Case

The municipality of Mordano recorded the highest UCO collection value for a total amount of 3.35 Mg per year or to 0.71 g per capita. The specific production per capita was calculated to provide a parameter of the correlation between UCO collections with the resident population (Figure 6).

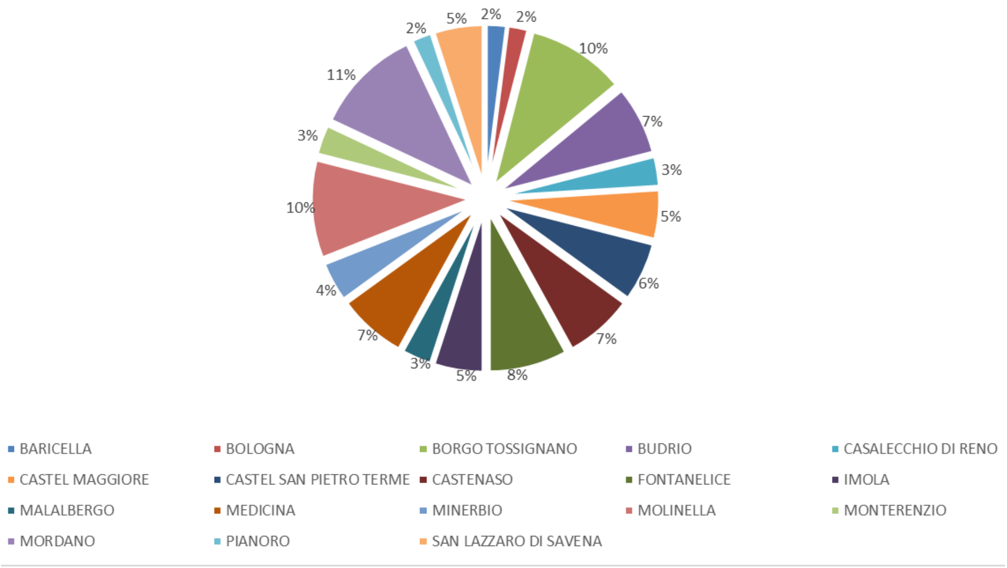

Figure 6. UCO specific production per capita in the selected municipalities.

The value recorded in Mordano was used as baseline for all the other municipalities to calculate the potential amount of collectible UCO. If all of the other municipalities would collect the same UCO per capita, a potential growth of 486.50 Mg (more than three times) would be possible. Figure 7 shows the current collection rates (per capita) and the additional production for all the municipalities within the case study area.

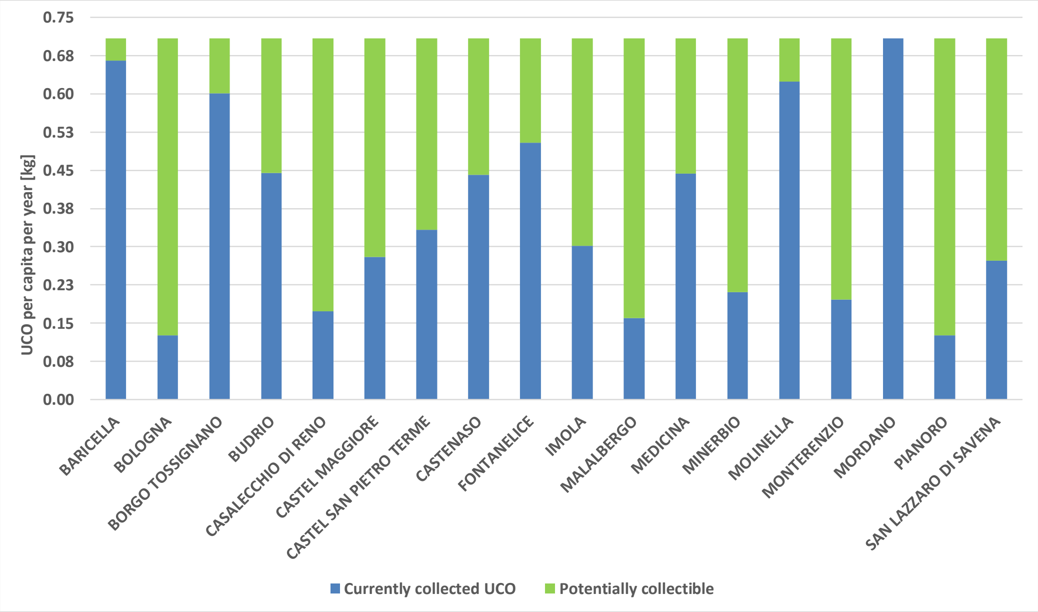

Figure 7. Collected and potentially collectible UCO per capita in the 2013–2014 biennium.

The new UCO amount introduced in the 46 weeks identified in the S2 scenario, represents the sum of that currently collected with the potentially collectible UCO. The weekly average amount from S2 to S3 was increased from 3.18 Mg to 10.34 Mg.

This amount of UCO would allow ensuring enough organic matter for 38 weeks out of the 46 where the threshold value of 30 Mg·day^{-1} was exceeded. Figure 8 shows that these eight weeks are concentrated in the last quarter of the year. This is mainly explained by the limited capacity to forecast the supply since both the energy crops and the by-products are characterized by a remarkable seasonality, with a limited availability in certain periods of the year, and by the structural weaknesses of the by-products market that is still fragmented and unstable. In this scenario the corn area would decrease from the 182.20 ha·year^{-1} of scenario S1 to 92.7 ha·year^{-1} of scenario S3 with a land savings of 49.1% (Table 1).

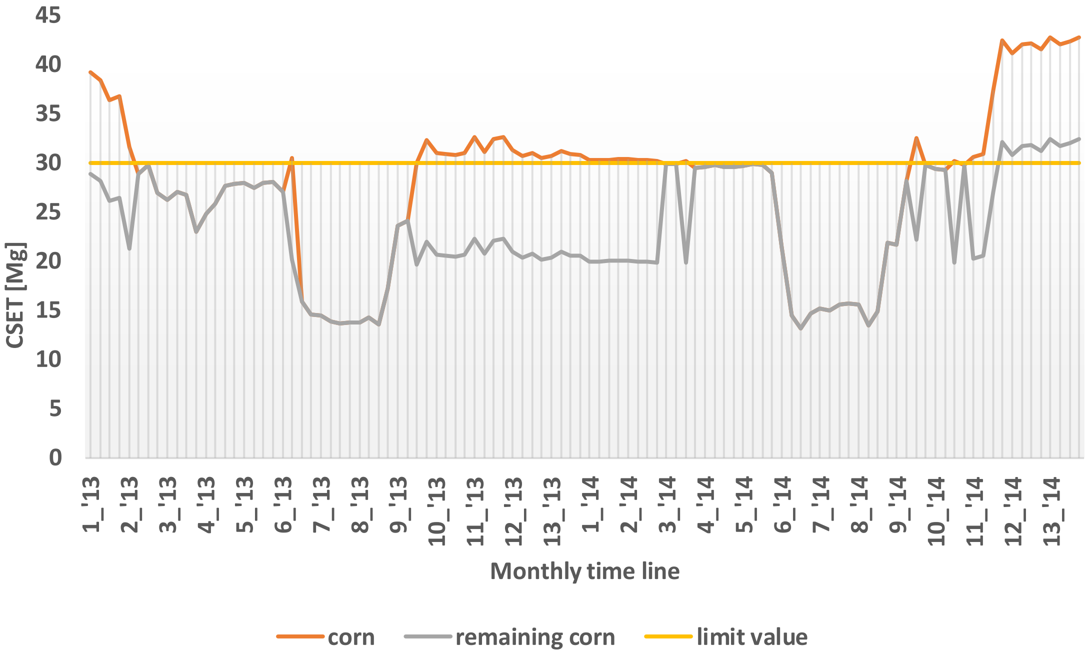

Figure 8. Corn required in the weeks exceeding the threshold value within S3.

Table 1. Summary of the three scenarios.

2013-2014 Average	S1	S2	S3
$C_{TOT,C}$ **[Mg per year]**	10,020.70	8450.20	5097.70
LU [ha per year]	182.20	155.30	92.70
LU_d **[ha per day]**	0.50	0.43	0.25
UCO collected [Mg per year]	0.00	146.30	486.50
UCO fed plant [Mg per year]	0.00	146.30	486.50
Land save [ha per year]	0.00	26.90	89.50

3.4. Economic Assessment

For a biogas entrepreneur, the average cost of feedstock (C_A) represents one of the most important parameters. In the economic assessment, the costs of all the feedstocks, with the exception of those of UCO, are fixed. Similarly, the market price of all the inputs remain the same under the three scenarios. Considering that in S2 and S3 the cost of UCO is equal to zero, the main variable is represented by the quantity of biomass.

In the case of the substitution of corn with UCO, the potential savings lead to a reduction of the production cost from € 0.61 million (scenario S1) to € 0.43 million (scenario S3) (Table 2).

The initial investment cost (C_I) results an unvaried item in the three scenarios since the biogas plant was already built. For the same reason also the management cost (C_G) remained unchanged.

With the biogas plant under operation and with a fixed electricity conversion, it was possible to calculate the plant revenue that results unvaried in the three scenarios.

NPV increased from €1.1 million (1,118,826.45) in S1 to €1.2 million (1,170,645.91) in S2 to €1.3 million (1,291,123.50) in S3.

The economic profitability of energy recovery from UCO is confirmed also from the *MS* value. In the S2 and S3 scenarios the substitution of corn with UCO allowed savings for €51,820 and €172,297.

Similarly, S2 and S3 were characterized by a positive *PO* value. If compared with the UCO market price of €490 per Mg the increased value of *PO* might find two different explanations. On the one hand the growth can be explained with the new allocation of UCO that would lead to a reduction of the price paid by recovery companies to regenerate it, thanks to the maximization of the present value and of the net benefits, and to the increase of the collectible quantity. On the other hand, the growth of the value of *PO* can be explained as the additional collection of UCO stimulated by a higher demand.

Table 2. Economic assessment overview results.

Value	**S1**	**S2**	**S3**
C_A [M€]	0.61	0.56	0.43
C_I [M€]	0.21	0.21	0.21
C_g [M€ (kWh)$^{-1}$]	0.23	0.23	0.23
C_T [M€]	1.1	1.0	0.89
R_T [M€]	2.1	2.1	2.1
NPV [M€]	1.1	1.2	1.3
MS [M€]	0.0	0.05	0.17
PO [€ Mg^{-1}]	0.0	350	350

4. Conclusions

The paper aimed to assess the technical and economic feasibility of the substitution of energy crops with UCO in AD with particular emphasis on the potential implications on land use. To carry out the analysis a full-scale plant performing AD was monitored for two years, three scenarios to evaluate the energy and environmental impact of the introduction of UCO were developed, and an economic assessment to estimate the cost-effectiveness and the potential income generation of the biogas system was performed.

Results suggest that the introduction of UCO in the feeding mix of the biogas plant could lead to land saving up to 50%. The use of UCO would allow to maintain a stable production of energy along the year, to mitigate the environmental impact of biogas production (less land used for the production of energy crops), and to ensure economic benefits for farmers (an additional source of revenue and reduced costs for biomass collection).

The partial substitution of ECs with UCO is technically feasible and economically viable with a major constraint put in place by the current legislative framework that limits the collection and the utilization of UCO for anaerobic digestion. Policy interventions should be aimed at removing the barriers that currently limit UCO collection and reuse in biogas energy systems.

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Chapter 2

Used cooking oil in bioenergy systems: a comparative analysis[2].

Abstract: Used cooking oil can be considered either a waste product with negative effects on the environment or a resource if part of a renewable energy system. This paper investigates the technical feasibility of incorporating used cooking oil into bioenergy systems in two case studies (Emilia Romagna-Italy and Missouri). A comparative analysis was used to simulate the best way to reuse and valorize used cooking oil successfully and to investigate policies that could be put in place to be able to implement the use of this resource for bioenergy systems. Used cooking oil can reduce the agricultural land use and better stimulate the local use of the resources. Policy intervention to increase the public-private relationship and the concern about economic and environmental benefits are also necessary.

Keywords: Bioenergy, energy policy, used cooking oil, land use.

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[2] This chapter represents a draft version of an article aimed to be submitted to Energy Policy. Authors will include Erika Carnevale (Department of Agricultural and Food Sciences, University of Bologna), Thomas G. Johnson (University of Missouri), Giovanni Molari (Department of Agricultural and Food Sciences, University of Bologna) and Matteo Vittuari (Department of Agricultural and Food Sciences, University of Bologna).

1. Introduction

The rapidly growing world of energy use and limited fossil sources (IEA, 2016) has enlarged the interest in bio-economy in the United States (US) and in the European Union (EU). At present, one of the bio-economy's key sectors is represented by bioenergy that offers an avenue toward energy independence, more sustainable solutions, and creating new business opportunities in rural and urban areas (Van Stappen et al. 2011; Johnson and Altman, 2014).

The bioenergy sector is growing simultaneously with rising competition for the use of agricultural land for the production of biomass, food, feed, and fiber (Sturmer et al. 2013; Tomei and Helliwell, 2016). Together with rising interests in bioenergy, concerns about its sustainability become more prominent along with food security, greenhouse gas (GHG), emission balances, and biodiversity impacts being discussed critically (OEKO, 2012; Scarlat, 2011; Shubert and Blash, 2010).

A potential negative consequence of expanding energy crops (ECs) production, is that farmers have an incentive to convert grassland and forests into cropland (Searchinger et al., 2008). Moreover, criticism of expanding ECs is exacerbated also by concerns about the nexus of food, energy and environment (Eaves, 2017; Tilman, 2009), and price competition in the commodity markets (ERS, 2008).

Bioenergy can partially mitigate climate change and generate social and economic benefits but in the US and EU, the effect on agricultural land value through agricultural land expansion, has been discussed (Molari et al. 2014; Lotzen-Campen et al. 2010; Wright, 2006).

For instance, the mandatory US Renewable Fuel Standard 2 (RFS2) legislation has prescribed the goals of federal biofuel production to be 36.0 billion gallons by 2022 (Brakmort, 2015). According to several authors this strategy fails to consider the long-term needs for fertile land to meet future food demands and the need to abate the indirect GHG impacts that would be created when land now used in grain production is diverted for biofuel use (Gelfand et al. 2013; Plevin et al. 2015; Searchinger et al. 2008; Tonini et al. 2012; Valin et al. 2015). At the same time the EU, with the Directive on Electricity

Production from Renewable Energy Sources and with the alternative fuel strategy, is committed to increasing the proportion of renewable energy to limit GHG production and promoting clean transportation fuel (EU, 2009; EU, 2014). In the EU 18% of all electricity is renewable with two-thirds coming from biomass use (IEA, 2010). Simulation models predict that 17–21 Mha of additional land would have to be converted to ECs production to meet the targets of the bioenergy share set by EU policies for 2020 (Banse and Grethe, 2008; Ozdemir et al. 2017). The EU targets for all countries to assure 20% of energy and 10% of transport energy consumption from renewables by 2020, are being strengthened to speed up the reduction of CO^2 emissions and cut output by 40% by 2030 (EC, 2016).

GHG reduction and agricultural land use issues represent key challenges for food system and energy sustainability (UN, 2015). Potential options to meet these goals include the short supply chain (SSC) approach, originally applied in a food market context and designed in the EU sub-program for rural development as a short transport distance, (Kneafsey et al. 2013) and later applied for bio-liquid produced by biomass and embodied in the EU Directive 2009/30/CE (EU, 2009b). The (SSC) can stimulate the use of locally available resources, and the transformation of energy sources to include waste streams (Cuéllar, 2010; Vittuari et al. 2016) to better achieve energy efficiency.

Human activities, including changes in lifestyles and consumption patterns have resulted in a growing anthropomorphic carbon footprint and rising rates of solid waste generation (Demirbas, 2011; Bunning, 2014; Hajilou et al. 2014). Moreover, with economic development and increased urbanization, people tend to move toward a western diet; increasing their fats, oils, and grease consumption, thus global consumption is rising (Vinyes et al. 2013).

From a variety of waste sources originating in the food system, the used cooking oil (UCO) was considered in this study. UCO is a kitchen waste and by-product generated daily from agro-food industries, restaurants, and homes which is available on a large scale (Knothe and Steidly 2009; Williams et al. 2012).

It is well recognized in the US and the EU as a potentially important input in biodiesel production, (Zang et al. 2003b; Li et al. 2011) for methyl ester synthesis (Cvengroš and Cvengrošová, 2004) and in co-digestion for biogas and methane production (Martín-González et al. 2010). Where the opportunities to recover and reuse the UCO for its energy content are feasible, social, environmental, and economic benefits can be realized (Zhang et al. 2003; Wallace et al. 2017; Carnevale et al. 2017).

One of the obstacles affecting UCO availability is the collection and recycling system that depends on a number of key factors such as economic profit, environmental awareness by local authorities, the commitment to promoting environmental measures, disposal technology, as well as geographic and policy barriers (César et al. 2017; Karmee, 2017). Furthermore, the feedstock costs, which comprise approximately 70-95% of total operating costs, affect the feasibility of biodiesel production (Mangesh, 2006; Millinger, 2016). Other important barriers to consider in bioenergy production are biomass availability and seasonality.

This research aims to analyze the effects substituting used cooking oil for energy crops on agricultural land use and to evaluate the feasibility of alternative policy interventions designed to enhance the UCO short supply chain. This research is based on two case studies in EU and US respectively, designed to identify the key conditions which determine the nature and magnitudes of these effects.

2. Method

For both case studies the research design involves 10 phases that are linked by the replacement of ECs with UCO in the bioenergy system plants in the two case study regions (Figure 1).

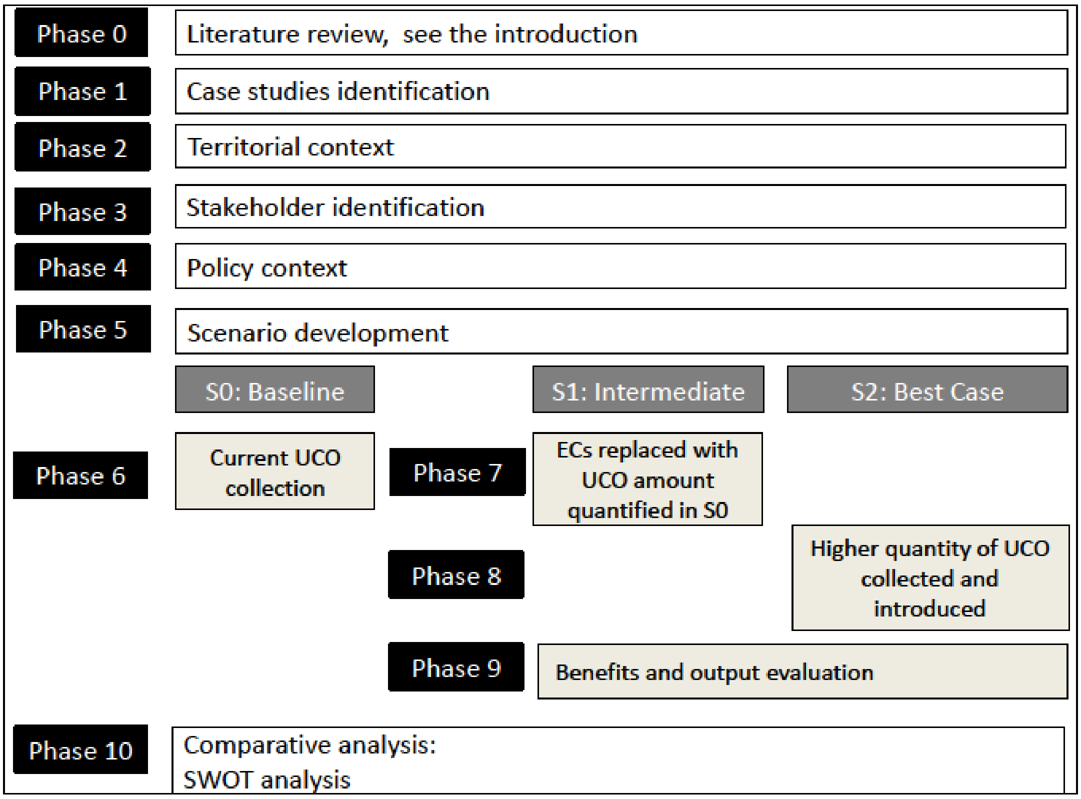

Figure 1. Research design

2.1. Phase 1: Case studies identification

The case studies were carried out in an Italian region, Emilia Romagna (ER), and a US state, Missouri (MO). A comparison between a region and a state has relevance in relation to the structure of energy system and governance. For instance the Italian energy policy is handled concurrently between the state and regions. In the case of energy production, transport and distribution, regions hold the administrative decision power. In contrast to the Italian context, in MO, the major administrative, planning, and decision making power is at the federal level. Furthermore, the case studies are characterized by different renewable energy production systems, farm-based biogas in the first case and biofuel refinery in the second case.

These two areas also share key common features, such as similar population size, gross domestic production per capita and number of agricultural farm, the percentage of the total agricultural area devoted to crop production and the intensity of biomass based energy production.

Furthermore, the EU decisions and directives like the US federal planning and programs, steer in both cases the national, regional and local policy agenda.

Table 1

Case studies features.

Source: Author's elaboration.

Study Area	**Emilia Romagna**	**Missouri**
Total Population [M]	4.4[3a]	6.0[4b]
Density [people/km^2]	198.1	33.7
Area typology	Semi-rural area	Rural[5c]
Cropland on total land (%)	78.0[6d]	76. 0[7e]
GDP per capita [$]	42,000[8f]	45,000
Agricultural GDP	5.8[8 f]	9.1[5 9h]
Agricultural farms	73,5006[d]	96,0007[e]
Governance structure	Semi-regionalised	Federate State
Energy consumption by sector [%]	Industrial (28.0), Transportation (28.0), Residential (25.0), Service (16.0) Agricultural (3.0)[10i]	Residential (29.4), Transportation (29.1), Commercial (22.4), Industrial (19)[11l]
Electricity production by source [%]	Renewable (36.0)	Coal (83.5), Nuclear (11.4) Hydroelectric (3.0), gas (1.6), Petroleum (0.4) Renewable (0.1)[11]
Available biomass resources	Agricultural dedicated crops, agricultural by-products, forestry by products, solid waste	Agricultural dedicated crops, seed corn, solid waste for landfill, wood[12j]

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[3] Population data statistics Emilia Romagna website: http://demo.istat.it/bilmens201gen/index02.html

[4] Population data Missouri website: http://www.census.gov/2010census/data/apportionment-pop-tex.php

[5] Missouri Census Data Canter http://mcdc.missouri.edu/TenThings/urbanrural.shtml

[6] Emilia Romagna website: http://agricoltura.regione.emilia-romagna.it/entra-in-regione/statistica-e-osservatorio/la-struttura-delle-aziende-agricole

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[9] Farmland Information Centre: http://www.farmlandinfo.org/statistics/missouri#Census of Agriculture

[10] Scapinelli, 2016

[11] U.S. Energy Information Administration, Independent Statistic & Analysis website: www.eia.gov

[12] Rodney J., Fink and Ross L. Fink, 2005. An Assessment of Biomass Feedstock Availability in Missouri. United States Department of Energy Office of Biomass Programs.

2.2. Phase 2: Territorial context

2.2.1. Emilia Romagna

After the EU Directive 2009/29/CE to enhance the sustainability of the biomass production and use in several bioenergy system, the Italian government adopt the principle of SSC of biomass availability for energy production approved with the financial law n. 296 in the year 2007. The arrangement was founded by MIPAAF (Ministry of Agriculture, Food and Forestry Policies) circular of 29 November 2010 that defined the operating mode to allow the biomass traceability in order for farmers to request "green certificates" if the biomass come from a SSC. The purpose has been to develop a more sustainable electricity production, increase biomass and agricultural by-product use and to facilitate the development of local energy system (Mela and Canali, 2014). This national strategic document, defines the sustainability of biomass-based for biofuel and biogas plants, to procure biomass for energy production within an area with a diameter of 70 km. The SSC principle represented the basis for the Italian case study area identification.

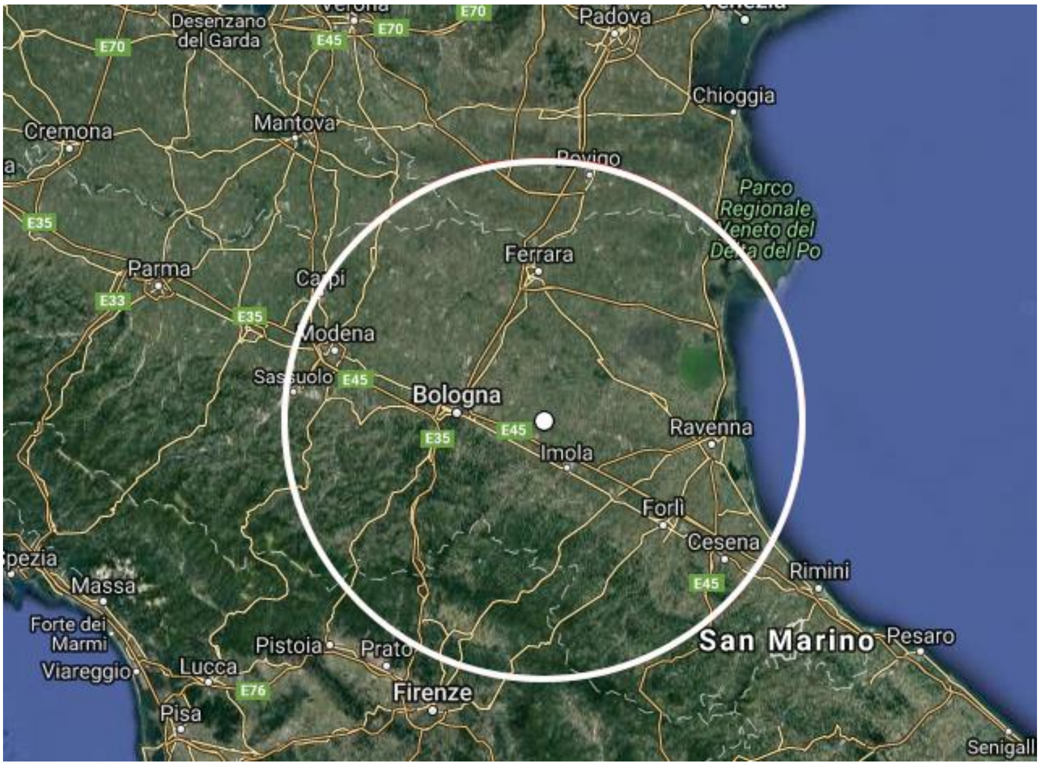

Figure 2. Emilia Romagna case study area, 70 km radius

Public policies have played an important role in stimulating and shaping the spread of biogas plants with a feed-in tariff system following the European Renewable Energy Directive (2009/28/EC), Regulation 1774/2002 on the use of animal by-products, and the Nitrates Directive (91/676/EEC).

The ER agricultural sector is mainly directed toward anaerobic digestion (AD) with 147 total plants which supply 10.45% of total electrical energy produced (Mela and Canali, 2014). Of these, 26 biogas plants are operating inside the case study area (Figure 2).

Since SSC principle to be respected must be calculated with the biogas plant in the exactly center of an area with 70 km in diameter, just four plant are located in the center of that area.

Table 2

Technology details of the four biogas plants taken into consideration in the ER case study area.

Source: Author's elaboration.

Parameters	**Plant 1**	**Plant 2**	**Plant 3**	**Plant 4**
Process	Wet	Semi-dry	Wet	Wet
Process temperature [°C]	38°- 40°	38°- 40°	38°- 41°	44°- 47°
Electrical power [kW]	999	999	999	999
Incentives [€/kWh]	0.28	0.28	0.28	0.28

The total load (TL) expressed in Mg year - wet basis – for each biogas plant, was calculated like the daily biomass of about 37 Mg day.

Furthermore, the biogas potential was calculated as the biochemical methane potential (BMP) assumed for corn equal to 95 $Nm^3CH_4 \cdot Mg$ wet basis, and multiplied for the total corn (T_{CORN}) used by each biogas plant considering the 30% of volatile solids (VS).

2.2.2 Missouri

The MO Department of Agriculture administers the MO Qualified Biodiesel Producer Incentive Fund, which was established in 2002 to encourage biodiesel production.

Section 142.031 of the MO Statutes for biofuel production provides that subject to appropriation, biodiesel produced in the state by a facility that is at least 51% owned by MO agricultural producers or which uses feedstock that is at least 80% of MO origin, are eligible for a grant in any fiscal year. Finally, the entire amount of feedstock must be originated in the US.

Currently ten biodiesel and seven ethanol plants make MO one of the most important states in biofuel total production contributing to around 3% of the total US biofuel production.

Table 3

US Biofuel total capacity.

Source: Author's elaboration.

US Biofuel Total Capacity [Mg year]			
Biodiesel		**Ethanol**	
US	MO	US	MO
$9.18 \cdot 10^6$	$0.75 \cdot 10^6$	$47.24 \cdot 10^6$	$0.74 \cdot 10^6$

Biodiesel can be produced from a variety of vegetable oils or animal fat sources and thereby provide some protection against volatility in supply for a single commodity, though not against a general rise in the prices of oils and fats.

Several biomasses are recognized by Renewable Fuel Standard 2 program, according to the technological process and fuel category that produces biofuel; oil, fats and grease are well recognized as feedstock for biodiesel. However the major feedstock in the MO continues to be soybean oil. As a result the industry risks periods when it becomes feedstock-constrained, a situation not helped by the recent widespread transfer of soy acres into corn (Massey et al. 2015).

The principle of SSC of biomass availability was applied also for the MO case study.

The plant under analysis is a typical system for producing biodiesel from soybean oil. It is located in the middle of MO, specifically in Mexico City.

Appling the SSC principle in the MO Case study area, the biomass supply area is shown in Figure 3. This area includes the metropolitan area of Columbia (Figure 3).

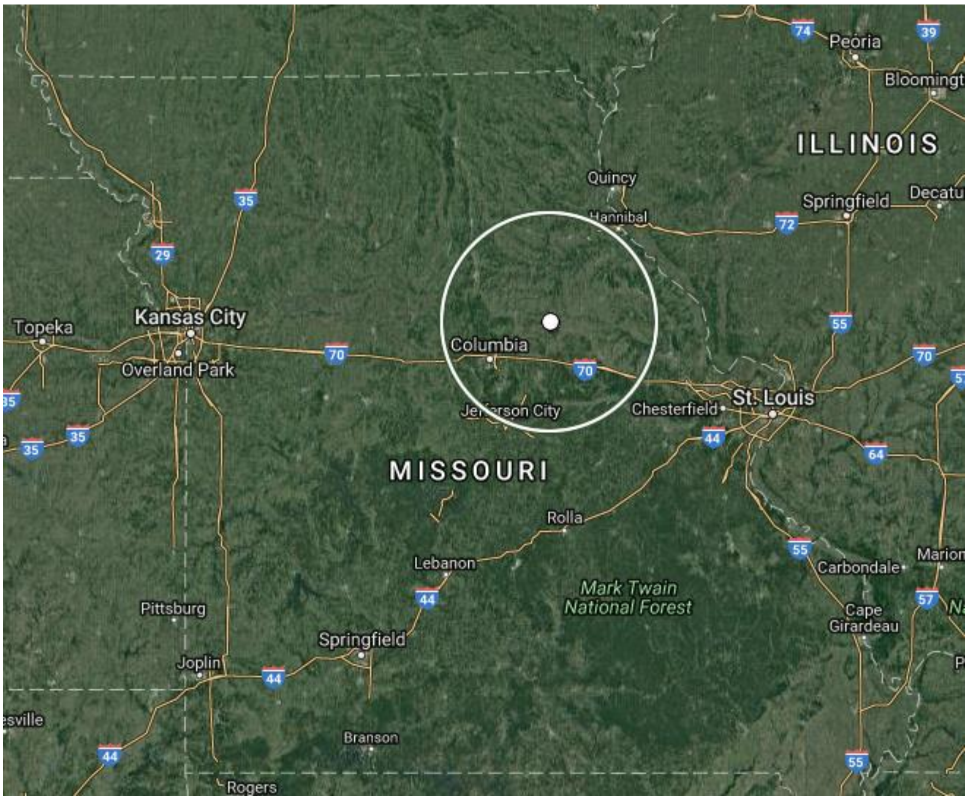

Figure 3. Missouri case study area, and SSC 70 km radius

2.3. *Phase 3: Stakeholder identification*

To identify the participants in this case study, a snowball sampling method was used (Morse and Niehaus, 2016). A purposive list of participants was created based on policies and procedures that took place within the context of biogas and biofuel production. Then, the other participants were identified personally by these first round participants. The participants came from the closest level of policy or issues. For each identified participant, the optimal data gathering method (i.e. semi-structured interview, interview and survey) was also considered, established and addressed. In both cases participant were divided into two stakeholders groups— were identified "primary" and "secondary" stakeholders.

Primary stakeholders are defined as those with a direct interest of the issues because they have business connections, or because they are involved in the policy process. The secondary stakeholders have been defined as those with a more indirect interest, such as those involved in the public institutions.

2.4. Phase 4: Policy context

2.4.1. Emilia Romagna

The reform of the Constitution which occurred in 2001, transformed Italy in a semi-regionalized governance system and art. 117 of the Constitution divided the legislative power between regions and the state, listing the subjects reserved by the state, those concurrently held by the state and regions - such as energy policy - and powers held by the regions only. The subsidiarity principle has allowed the regions to prepare their own renewable energy plan and to choose the strategy to use to achieve the EU energy targets. The regional goal for renewable energy share in gross final energy consumption 8.9% and the national goal are of 17% to pursuit by the 2020. Italy supported the anaerobic digestion by several financial supports like feed-in tariff, certificate and tax deductions (Cavicchi et al. 2014) and ER for their semi-rural region with significant agricultural diversification and profitable agricultural manufacturing sector also addressed their energy goal with biogas plants. The development of anaerobic digestion, has been a way to consolidated a by-products market and contribute to the EU second CAP pillar goals related to rural development by increasing farmers income and expanding multifunctional agriculture.

2.4.2. Missouri

MO is one of 29 states in the US that in the year 2008 approved the Clean Energy Act, also known as Proposition C, which repealed the state's existing voluntary renewable energy and energy efficiency objectives and replaced it with the Renewable Energy Standard (RES) policy. In MO, the RES policy requires investor-owners utilities to purchase 15% of their annual retail sales from eligible renewable energy technology sources by 2021. In the absence of direct public subsidies, and no requirements on municipal utilities or electrical cooperatives, the policy provides for renewable energy credits (REC) and a market price system with Locational Marginal Pricing to encourage the state's investor-owned utility companies to adopt renewable energy. The RECs are tradable, non-tangible energy commodities that represent proof that 1MWh of electricity were generated from an eligible renewable energy resource. The RES policy includes clean energy standards, which also recognize nuclear and low-polluting non-renewable energy sources, and establish renewable energy goals.

In 2008, Under the Energy Policy Act, and expanded under the Energy Independence and Security Act of 2007, a Renewable Fuel Standard became effective in MO. Despite the federal goal to produce significantly more renewable fuel to replace petroleum-based transportation fuel, heating oil or jet fuel, the federal tax credit for the biofuel producers expired in 2009. Before 2009, the tax credit was valued at $1.00 per gallon of agro-biodiesel (biodiesel produced from virgin agricultural products such as soybean oil or animal fats) and 50 cents per gallon of biodiesel produced from previously used agricultural products (e.g., recycled fried grease and oil).

To increase the blended biofuel consumption, MO introduced a tax credit for alternative infrastructure investment specifically fueling stations. In 2010 the MO Joint Committee weakened the RES by removing two clauses from the rules written by the Public Service Commission to carry out the law. Those clauses stipulated that, in order to meet the renewable standard, energy had to be delivered to MO and be sold to MO customers.

2.5. Phase 5: Scenario development

For each case studies analyzed, three scenarios named S0 "Baseline" S1 "Intermediate" and S2 "Best Case" were carried out.

S0 represents the current level of UCO collection. In the baseline scenario, the biogas and biodiesel plants do not utilize UCO. This scenario represents the actual situation in the bioenergy system. The UCO quantified in the baseline scenario is named UCOS0.

S1 is considered an intermediate scenario where the ECs currently used by the biogas and biodiesel plants under analysis, have been partially replaced with the UCOS0.

S2 represents the best scenario where a higher quantity of UCO (UCOS2) was assumed to be collected by the companies and introduced into the biogas and biofuel plants.

In ER area for the best case has been assumed the higher municipality collection amount, specifically Mordano municipality.

In MO for the best case scenario we assume that the UCO is collected in six metropolitan areas.

2.6. Phase 6: S0 Current UCO collection

2.6.1. S1 Emilia Romagna

The estimate of UCO quantities available has been based on previous research (Carnevale, et al. 2017). By extrapolating the average output of UCO per capita connects the data with the population in the present ER case study area, the current UCO was quantified (UCOS0).

The estimated quantities of UCO were based on real data obtained by questionnaires sent to A.R.P.A (Regional Environmental Protection Agency) and C.O.N.O.E. (Italian National Consortium for Mandatory Collection and Processing of Waste Vegetable and Animal Oils and Fat).

2.6.2. S1 Missouri

The estimate of UCO quantities was based on the first stakeholder group and by the annual Missouri State Recycling Program Report. Also the current UCO use and its disposal were partially estimated form semi-structured interviews with the experts specifically with the Columbia waste management office and Missouri natural resources department.

Policies and regulations from the level of the municipality up to the national level were examined for this information as well, and to understand the different entrepreneurs involved in the market.

Furthermore, according to the method used by the Department of Energy’s National Renewable Energy Laboratory (NREL) that sponsored a study on urban waste grease resources in 30 randomly selected metropolitan areas in the US (Wiltsee, 1998), the UCO variable equation for the Columbia city UCO collection was as follow:

$$f(UCO) = \alpha x + \beta \tag{1}$$

where the UCO depends of the population ($\boldsymbol{\beta}$) and UCO collected per each city analyzed (x).

The UCO quantity was analyzed in the metropolitan area which the definition is delineated by the Office of Management and Budget like Metropolitan and micropolitan statistical areas (metro and micro areas) are geographic entities delineated by the Office of Management and Budget (OMB) for use by Federal statistical agencies in collecting, tabulating, and publishing Federal statistics. The term "Core Based Statistical Area" is a collective term for both metro and micro areas.

The percent growth (PG) rate in Columbia was also taken into consideration in order to estimate the potential UCO market with the future population growing.

$$PG = \frac{V_{present} - V_{past}}{V_{past}} \times 100 \tag{2}$$

using this method, two UCO quantities were calculated for the:

UCO_C is the quantity of UCO produced currently in Columbia city;

UCO_{Cpg} is the quantity of UCO produced by Columbia considering the expected growth in city's population.

2.7. Phase 7: replacement of EC with the UCOS0

2.7.1 Emilia Romagna

The UCOS0 was supposed to be used to replace the same amount of corn utilizing the biogas plants. Assumed that UCO and corn had different methane potential the replacement has been based on the biochemical methane potential (BMP) value. Using the BMP value allowed the simulation replacement maintaining the same power potential (999 kW).

It was assumed a corn BMP value equal to 95 $Nm^3CH_4 \cdot Mg$ wet basis (considering a 30% of volatile solids on the load) and a UCO BMP value equal to 10.21 of corn BMP considering 99.76% of VS.

2.7.2 Missouri

The oil yields from the crops are always the key factor determining the suitability of a feedstock for biodiesel production. According to the literature reviewed, the quantity of biodiesel which can be produced from UCO can be estimated in a manner similar to that for biodiesel produced directly from soy oil. For the total soy oil (T_{SO}) used by the biodiesel refinery, the lipid esters density of soy oil 0.885 g/l^{-1} has been considered (Viola et al., 2010). An accuracy of one to one transformation of T_{SO} input in biodiesel mass was also assumed. The T_{SO} considering like a energy crops in this case study was replaced with UCO_C and $UCO_{Cpg.}$

Many factors influence the transesterification process, (i.e molar ratio, catalyst concentration, and temperature) but it was assumed a transesterification yield from UCO to biodiesel of 94% (Banerjee et al., 2014; Elkady et al., 2015).

To calculate the 94% biodiesel yield from UCO we first divided the UCO amount for the molecular soy oil weight (872.23 g/mol) and multiplied for the ester lipid mass 292 g/mol.

2.8. Phase 8: Higher quantity of UCO collected and introduced

2.8.1 Emilia Romagna

The hypothetical higher quantity of UCO (UCOS2) was calculated by multiplying the higher UCO collection rate per capita collected in the Mordano municipality by the total residential population in the case study area. The ECs amount replaced with the UCOS2 quantity follows the method explained in the phase 7.

2.8.2 Missouri

The higher UCO hypothetical quantity in MO case study (UCO_M) was quantified by the (e.g. 1) one considering in that case six metropolitan areas namely St. Louis, Kansas City, Springfield, Joplin, Columbia and St. Joseph. The equation two has been also applied for the future UCO amount collectible (UCO_{Mpg}) in the same area. The UCO_{Mpg} has taken in to account the population growth for five years.

The ECs replacement with the UCO_M and UCO_{Mpg} quantities, follow the method explained in phase 7.

2.9. Phase 9: Benefits and output evaluation

2.9.1. Emilia Romagna

The agricultural land use (LU), specifically the amount of hectares needed to produce the quantity of corn required to feed the four plants, was calculated in the ER case study. It was first calculated the total amount of corn used by the biogas plants (C_{TOT}) and divided by the average annual yield (AAY) of the corn.

An AAY for corn has been assumed like about 55 Mg ha^{-1}.

$$\mathrm{LU}\left[\frac{\mathrm{ha}}{\mathrm{year}}\right] = \sum_{xi}^{4} \frac{C_{TOT}}{AAY} \tag{4}$$

Moreover, the land use save (LUS) was calculated as the difference between the LU value for the S0 baseline scenario and the LU values in the S1 and S2 scenarios.

2.9.2. Missouri

In the MO case study the amount of land needed to supply the fuel demands depends on the type of biomass used. It was assumed an AAY of about 3.12 Mg ha^{-1} for soy beans per year (USDA; 2016). The total soy oil saved (T_{SS}) has been defined as the difference between the T_{SO} less the UCO_C, UCO_{Cpg}, UCO_M and UCO_{Mpg} respectively. Furthermore, it was assumed an average yield of soybean crashing to crude soy oil of around 18 – 20% (Tavares de Andrade et al., 2013). The LU amount was estimated as:

$$LU\left[\frac{ha}{year}\right] = \frac{T_{SO}}{AAY} \tag{5}$$

Moreover, the land use save (LUS) was calculated as the difference between the LU value for the S0 baseline scenario and the LU values in the S1 and S2 scenarios.

2.10. Phase 10: Comparative analysis

A comparative analysis of these very different regions and cultures was undertaken in order to highlight the roles of political context and problem solving skills in the achieving increased renewable energy production in a sustainable way in terms of agricultural land use change and UCO valorization. To compare this two energy system the Most-Similar and Most-Different Systems Designs (Orvis and Drogus, 2013) with policy analysis was taken into consideration. Moreover, the strength, weakness, opportunity and threats (SWOT) analysis was carried out and used like a tools.

The purpose of the comparative analysis has been to develop a basis for policy interventions suggestion in both cases study regions.

3. Results and Discussion

3.1 Case studies identification and territorial context results

3.1.1 Emilia Romagna

Figure 4 shows the total quantities of feed stock used by each biogas plant in ER case studies and expressed in percentage.

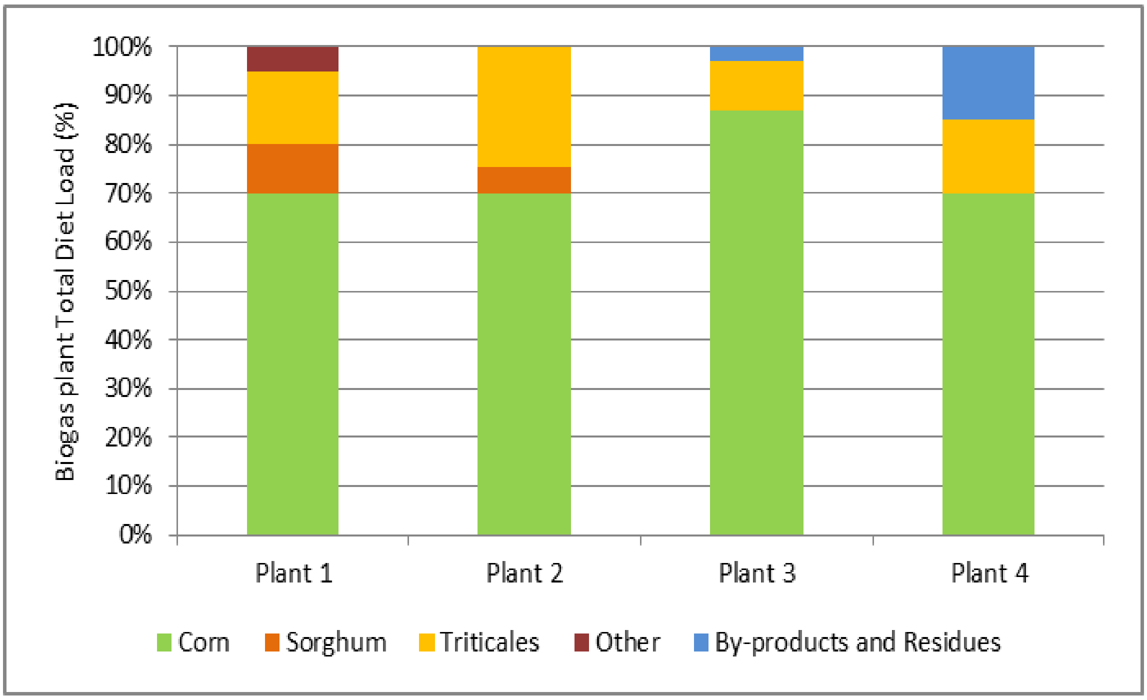

Figure 4. Total load, expressed in percentage, for the four biogas plants

Each biogas plant used 70% or more of corn per year. This amount corresponds to a 40,000 Mg year on a total load of 54,000 Mg year. Two biogas plants used by-products but in a quantity less than 10% of the total biogas plants requirements. Sorghum and triticale were not considered ECs in this research because of the very low quantities used.

Table 4

Emilia Romagna anaerobic digestion plants results.

Source: Author's elaboration

Plants	**Total digester volume [m^3]**	**Total corn [Mg year]**	**Volumetric organic load [Mg/m^3/year^{-1}]**	**Methane Production [Nm^{3}Ch$_4$·Mg (SV)]**
Plant 1	$2.50\cdot10^3$	$9.45\cdot10^3$	$1.08\cdot10^2$	$2.69\cdot10^6$
Plant 2	$1.60\cdot10^3$	$9.40\cdot10^3$	$1.68\cdot10^2$	$2.68\cdot10^6$
Plant 3	$2.92\cdot10^3$	$1.17\cdot10^4$	$1.15\cdot10^2$	$3.34\cdot10^6$
Plant 4	$3.00\cdot10^2$	$9.45\cdot10^3$	89.81	$2.69\cdot10^6$

3.1.2 Missouri

Bioenergy production in MO includes alternative liquid fuels in the form on ethanol and biodiesel with a contribution of a total US biofuel production on around 3%. MO State has the fourth largest biodiesel production capacity in the nation with nine biodiesel plant and one more under construction for a total of 475 million gallon per year produced.

Table 5

Missouri contribution in US biofuel.

Source: Author's elaboration.

US Biofuel Plants			
Type	**n. plants**	**Total capacity (Mg year)**	**Production (%)**
Biodiesel US	166	$9.18 \cdot 10^6$	14.84
Biodiesel MO	9	$7.52 \cdot 10^5$	1.22
Ethanol US	231	$4.72 \cdot 10^6$	85.15
Ethanol US	7	$7.43 \cdot 10^5$	1.34

The 22.12% of the total biodiesel produced in Missouri comes from the plant under analysis. The business structure is a company in a partnership with LLC, Archer Daniels Midland (ADM); Ray-Carroll County Grain Growers, Inc.; MFA Oil Co.; and GROWMARK, Inc. Missouri Soybean Association, as well as a director of National Biodiesel Border and about 400 agricultural producers.

The location was also strategic to be close to other facilities and feedstock was chosen for the adequate supplies of feedstock.

3.2. Stakeholders results

In ER case study, involved the C.O.N.O.E., the UCO collection companies and the biogas plant entrepreneurs. The Missouri case study involved the biodiesel companies and the

UCO collection companies, the National Biodiesel Board. For this first group, survey gathering data method was used.

The ER case study also involved the A.R.P., the Medicina mayor and the H.E.R.A. the multi-utility holding group. The MO study also involved the University of Missouri Campus dining services, the Ameren Corporation, which is the largest investor-owned electric and gas utility, the MO Division of Energy, the ADM Company, the MO State Recycling Program, MO Department of Natural Resources, and the MO Energy Action Coalition, one soy beans farmer. For this second group, the semi-structured interview method was used.

3.3. Policy results

3.3.1 European Union versus Emilia Romagna

Renewable energy production has been widely promoted in the EU as an effective measure counteracting economic and social challenges facing rural areas especially those with declining agriculture economies. The EU policy framework for renewable energy production and consumption could be summarizing with one policy document, the Renewable Energy Directive (RED) 2009/28/EC. The RED legislation for biofuel and electricity production sets binding targets for renewable energy by 2020. The targets for the EU is at least a 20% share of Community gross final energy consumption from renewable sources and at least 10% of final consumption for transport from biofuel. All Member States must establish their national renewable energy action plan showing which action they intend to take to meet EU renewable targets. These plans include sectorial targets for electricity, heating and cooling and transport; planned policy measures and the different mix of renewables technologies they expect to employ. Furthermore the creation of the EU internal energy market creates opportunities for countries to work together through cooperation mechanisms like statistical transfer, joint project and joint support schemes.

For biofuel production, the RED ensure that use of biofuels (used in transport) and bio liquids (used for electricity and heating) has been done in a way that guarantees real carbon saving and protects the biodiversity. To be considered sustainable, biofuels must achieve GHG savings of at least 35% in comparison to fossil fuels. This savings requirement rises to 50% in 2017 and rises again to 60% in 2018 with a clear enforcement of renewable energy policy.

In June 2010 the European Commission adopted a package on sustainability criteria of biofuels to fulfil the transport target in the 2009 RED Directive. These criteria are taken from the RED Directive in the 17, 18 and 19 articles and are related to two main issues, GHG saving and land protection.

For the GHG saving all life cycle emissions were taken into account and land restriction are connected with land with high carbon stock and with high biodiversity value. This includes land that in or after January 2008 had the following status of primary forest, designated as natural protected area, and highly biodiverse grassland. The indirect land use change (ILUC) were not introduced but the European commission propose to enhance the incentives for the best performing biofuel. Sustainability criteria also have included the agro-environmental practices common rules under the Common Agricultural Policy (CAP) and established in accordance with the minimum requirement for a good agricultural and environmental condition. The EU sustainable agricultural production is regulated through the environmental cross-compliance requirements in the CAP.

Finally, the RED Directive introduced the social sustainability criteria that took into consideration in the Community and in third countries, the impact of biofuel policy on the availability of foodstuff at affordable price. The EU directives were finally adopted in each member state.

In Italy the reform of the Constitution occurred in 2001, transformed Italy in a semi-regionalized governance system and the subsidiary principle has allowed the regions to prepare their renewable energy plan and to decide which strategies achieving the EU energy targets.

ER is a semi-rural area with agricultural diversification and developed agricultural manufacturing sector, which permitted the biogas plants from biomass and by-products to be productive and effective. Furthermore, the most common ownership structure of biogas plants is farm-based and either locally or municipally based. The sustainability of anaerobic digestion system was hardly discussed and the sustainability purpose create a chain of custody approach requiring feedstock/biomass producers and processors to keep track of certified biomass using for auditing purposes. Moreover, the biomass traceability is necessary for the biogas entrepreneur to require the green certificate attesting the short supply chain. For a more sustainable production, the new incentives for the biogas plant are related with the plant size, the biomass and by-products used and with the transport system related with GHG save

The energy field is oriented to small scale biogas plant, biomass diversification with by-product use in order to reduce energy crops and short supply chain to reduce the transport GHG emission.

Innovation to the system are been implemented to upgraded biogas plants for methane production inject it into natural gas grid. In a range of organic matter allowed to use in an AD, the UCO is not considered. The EU classified the UCO like a waste and not like a by-product. The EU guideline CE 1774/2002 banned the UCO in animal feed after the epidemic BSE and to ensure the healthy food system. Moreover, the Directive 2008/98 oriented to stimulate the use of the waste based on the green economy principles.

At national level the D.lgs 2006 n. 152 require the obligation to dispose and recycle the UCO. To carry out the regulation, the UCO producers can address their need to the CONOE. The CONOE assignment was to manage waste produced in the professional sector on the whole national territory, to reduce the dispersion into the environment of the UCO and limited its pollution potential and risks to public health. With the D.lgs 22/97 the Consortium C.O.N.O.E. was created and 13 national Consortium and more that 300 collectors and regeneration company are been participated in that system. Specifically, In Emilia Romagna 23 collection companies and six regeneration companies are working.

Different urbanization that decrease the infrastructure cost and transport

3.3.2. United Stated versus Missouri

The situation is different in the US where a federal Renewable Energy policy is not yet fully implemented. The Renewable Energy Standard (RPS) for electricity production by renewable energy is a national act and each state can adopted and implemented it voluntarily. The RES represents an obligation for the electricity supply companies to produce a specific fraction of their electricity from renewable source. Unlike the feed-in-tariff used by the EU, the RES is market oriented and states that adopted it often rely on renewable energy certificate trading programs. The obligatory consumption of given biofuel volumes was first implemented with the Inclusion of Renewable Fuel Standards (RFS1) in the Energy Policy Act of 2005. The objective was to employ 4 billion gallons of renewables in transport fuels in 2006 and increment their share over the years.

In July 2010, the updated Renewable Fuel Standard (RFS2) went into effect finalizing proposals made with the Energy Independence and Security Act (EISA) of 2007. The EISA introduce four biofuel categories and established a specific mandate volumes for renewable fuel, advanced fuel, bio based diesel and cellulosic biofuel for an aggregate of 36 billion gallons of renewables to be used in transport fuels by 2022. With the RFS2 environmental sustainability standards were established and to further increased the biofuel production, the second-generation biofuel were incentivized. With the new alternative diesel standards was stimulated the uses of biofuel feedstocks like vegetable oil and animal fats.

Moreover the environmental sustainability standards have established the lifecycle GHG emission threshold for each of the RFS2 biofuel category and the indirect land use change was taken into account and constantly implemented by the federal Environmental Protection Agency (EPA). The vegetable oil and animal fats use for advanced biofuel received extra support for their low impact on indirect land use chance. EPA has more authority which is different from the EU where a common framework is established by member states. The EISA limited the land that the renewable fuel feedstocks may come from. Specifically excluded under the EISA definition are virgin agricultural land cleared or cultivated after December 19, 2007, as well as tree crops, tree residues, and other biomass materials obtained from federal lands. These restrictions are applicable to both domestic and foreign feedstock and biofuels producers.

To increase the renewable energy and energy efficiency, the MO states adopted the RES with the Missouri Clean Energy Act in 2008 with a mandatory renewable portfolio standard where 15% of total energy needs to come from renewable sources. The renewable energy credits represent the policy tools are not required that renewable production is inside the State. More attention to cost effective and not environmental benefits. The MO renewable Fuel Standard and Conservation Land Program was introduced in 2008 to increase blended gasoline consumption.

A tax credit for support the biofuel production and consumption was introduced. The biofuel producers and business owner or private citizen who invests in alternative fuel refueling property are eligible for the tax credit. Different approach for biofuel production where at least the 80% of the biomass used by the plant should be produced inside the state.

In the Midwest in general, including MO, the most common biodiesel production system is an integrated system were biodiesel plant runs with a homogenous feedstock throughout the year.

The homogenous feed stock is a strategical choice to promote efficiency and productivity plans that equates to reduce plant costs. The 70-80% of the total cost by the plants is nowadays represented by the feedstock market price. The biodiesel plants the use also UCO on animal fats like a feedstock are subject to disparities due to the nature of the process. There will always be some differences because UCO collections will never be the same. This can be overcome, certainly, but it requires that the preparation of the feedstock is overly conservative in removing all of the waste that cannot be converted to biodiesel. This will be consistent across much of the Midwest - Iowa, IL, etc. The integrated plants are centered in the Corn Belt. Moreover for the biodiesel plants that chose to use the waste and grease material are oriented on the animal fats for the huge quantity and stable collection

3.5. S0 baseline

3.5.1. Emilia Romagna

In the ER case study the average annual amount of UCO collected (UCOS0) by authorized companies was approximately 1,026 Mg year. Figure 6 shows the breakdown of the UCOS0 collected in the five metropolitan areas. The metro area with the higher resident population, Bologna, presented the higher share of collected UCO.

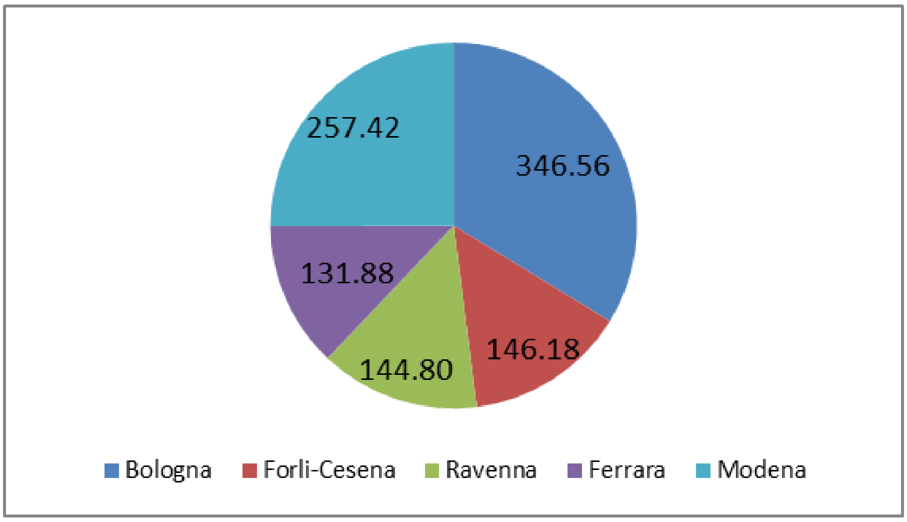

Figure 6. Currently UCO collection in the Emilia Romagna case study area

3.5.2. Missouri

Columbia City ordinances were analyzed and were found to include an ordinance which created a public-private partnership designed to prevent the discharge of grease into sewers. At National level no information were found on the City of Columbia UCO amount collection.

The City of Columbia is a University City and the campus provides a UCO collection service in the restaurants that are working inside the university campus. The collection service is offered by one company that also reported to the Campus Dining Centre the amount collected for each fiscal year.

The UCO is collected at seven locations on the campus and the private grease collection service collects the oil on a regular basis at no charge and uses it for a variety of applications.

For a while, one of the University's experimental farms (Bradford Farm) collected a small amount of the oil and converting it to bio-diesel for uses it on the farm.

In the 2015 fiscal year 35 Mg of UCO were purchased by the campus, of which an estimated 75-80% was discarded after use with the remainder being either absorbed by food or lost in production. The date also referred to the restaurant inside the Columbia campus and to better estimate the UCO produced in all restaurant located in Columbia metropolitan area, it was assumed that there is a linear relationship between the population and the UCO per city.

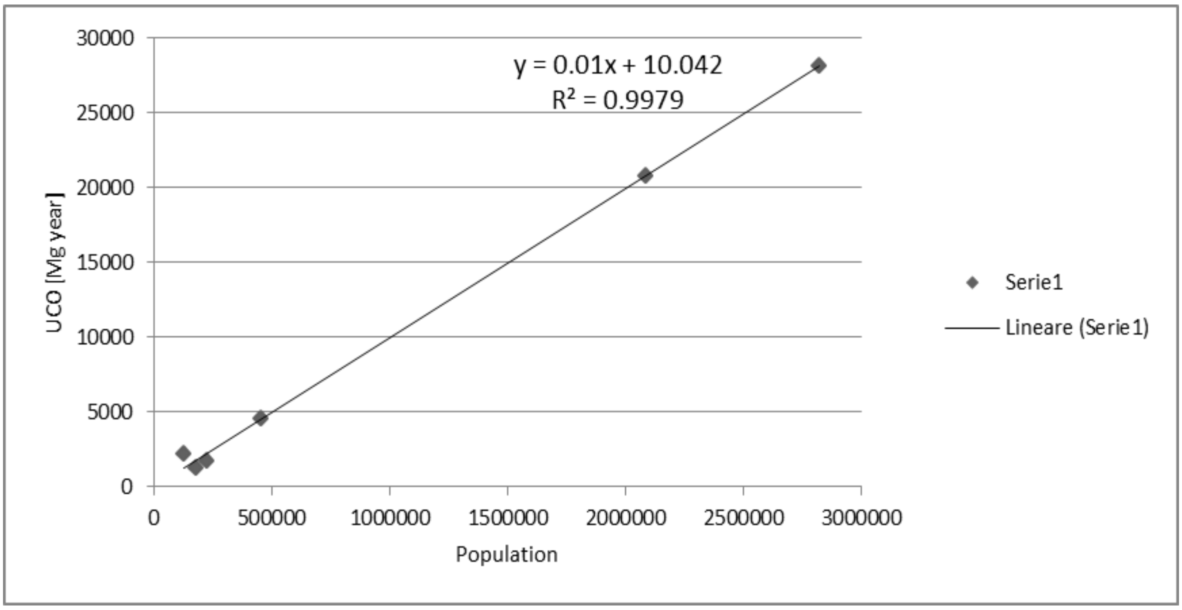

Figure 7. Regression plot

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The population growth from 2000 to 2016 was also considering the future potential of the UCO availability in Columbia.

Table 6

Columbia UCO quantification

Source: Author's elaboration.

Metro Area	Population	% Growth rate [2000-16]	Tot. UCO [Mg year]	Potential UCO [Mg year]
Columbia	$2.24 \cdot 10^5$	3.35	$2.23 \cdot 10^3$	$7.47 \cdot 10^3$

3.6. S1 Intermediate

3.6.1 Emilia Romagna

The replacement of corn with the UCO quantified in the S0 baseline was assumed to ensure unaltered valued for the total load, electrical power and energy production. As the biogas plant produced the same electrical power per year - 999kW - the UCOS0 were equally divided and distributed along the four biogas plants. 256 Mg of UCO were hypnotized to be introduced in each plant diet. The total corn used by each plant decreased for the same amount of UCO. Table 6 shows that the introduction of this matrix ensure a reduction of the quantity of corn and increase the methane potential.

Table 6

Emilia Romagna ECs replacement with UCO amount quantified in S0.

Source: Author's elaboration

Plants	Total digester volume [m^3]	Total corn [Mg year]	Total UCO [Mg year]	Volumetric organic load [Mg/m^3/year-^{1}]	Methane Production [Nm^{3}Ch$_4$·Mg^{-1}/SV]
Plant 1	$2.50 \cdot 10^3$	$9.20 \cdot 10^3$	$2.57 \cdot 10^2$	$1.89 \cdot 10^2$	$4.71 \cdot 10^5$
Plant 2	$1.60 \cdot 10^3$	$9.15 \cdot 10^3$	$2.57 \cdot 10^2$	$2.94 \cdot 10^2$	$4.69 \cdot 10^5$
Plant 3	$2.92 \cdot 10^3$	$11.49 \cdot 10^3$	$2.57 \cdot 10^2$	$1.83 \cdot 10^2$	$5.36 \cdot 10^5$
Plant 4	$3.00 \cdot 10^2$	$9.20 \cdot 10^3$	$2.57 \cdot 10^2$	$8.23 \cdot 10^2$	$4.71 \cdot 10^5$

3.6.2 Missouri

The replacement of the soy oil with the two UCO amounts quantify in the S0 baseline has been considering with the population growth of Columbia metro area as well.

Table 7

Missouri ECs replacement with UCO amount quantified in S0.

Source: Author's elaboration

Substitution	Biodiesel [Mg year]	UCO_C [Mg year]	UCO_{Cpg} [Mg year]	BM1 [Mg year]	BM2 [Mg year]
Co-operation	$1.67 \cdot 10^5$	$2.23 \cdot 10^3$	$7.47 \cdot 10^3$	$1.69 \cdot 10^5$	$1.74 \cdot 10^5$

3.7. Best Case

3.7.1 Emilia Romagna

The higher collection value was recorded in the municipality of Mordano for a total amount of 3.35 Mg per year or 0.71 g per capita. This specific parameter was correlated with the population of the metro areas analyzed to suppose the potential in collection in each area. If the other entire municipality would collect the same UCO amount per capita, a potential growth of 2,012 Mg would be possible.

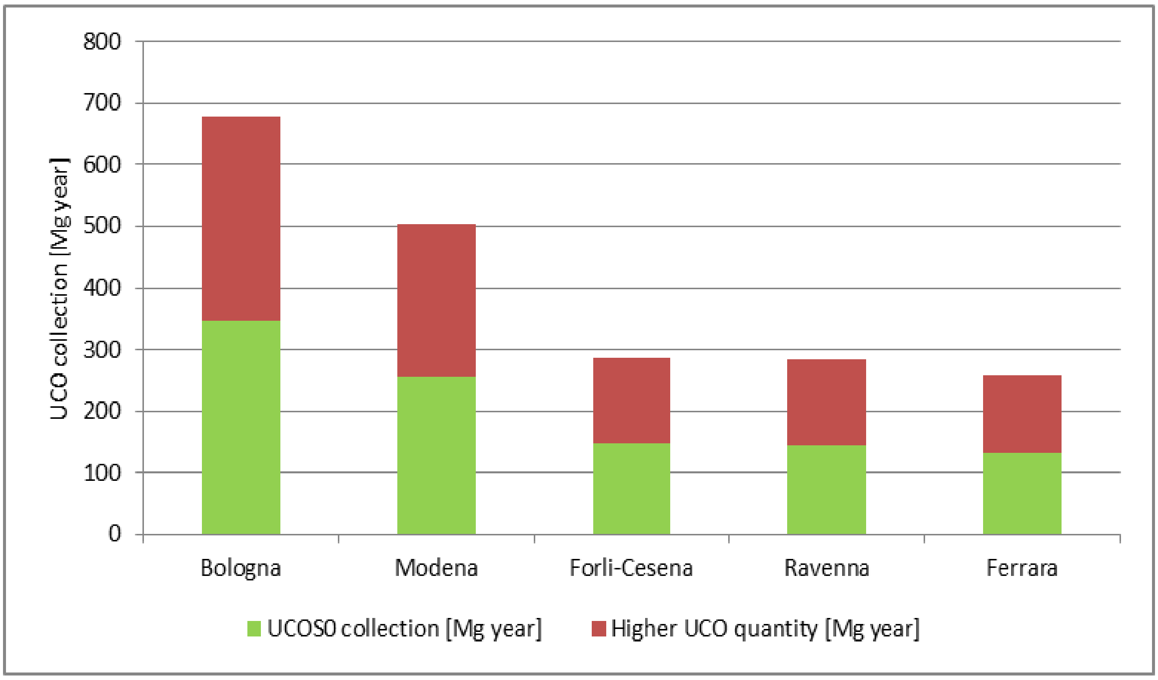

Figure 8. UCOS0 quantity and the potential collection if the collection trend was the same of the higher collection registered in Mordano

This new UCO amount was supposed to be introduced in the four biogas plant and it was equally divided with 502.50 Mg for each plant for a total of 2,020 Mg in a year. In comparison with the UCOS0, this new quantity increased about the double and the total corn decreased like the double as well. The methane production increased of about the 40% in comparison to the S1 Intermediary case.

Table 8

Emilia Romagna UCO potential collection and valorized in the anaerobic digestion plants

Source: Author's elaboration

Plants	**Total digester volume [m³]**	**Total corn [Mg year]**	**Total UCO [Mg year]**	**Volumetric organic load [Mg-1/m³/year]**	**Methane Production [Nm³Ch₄·Mg-1/SV]**
Plant 1	$2.50 \cdot 10^3$	$8.95 \cdot 10^3$	$5.03 \cdot 10^2$	$2.66 \cdot 10^2$	$6.66 \cdot 10^5$
Plant 2	$1.60 \cdot 10^3$	$8.90 \cdot 10^3$	$5.03 \cdot 10^2$	$4.15 \cdot 10^2$	$6.64 \cdot 10^5$
Plant 3	$2.92 \cdot 10^3$	$1.25 \cdot 10^4$	$5.03 \cdot 10^2$	$2.49 \cdot 10^2$	$7.30 \cdot 10^5$
Plant 4	$3.00 \cdot 10^2$	$8.95 \cdot 10^3$	$5.03 \cdot 10^2$	85.06	$6.65 \cdot 10^5$

3.7.2 Missouri

The information and data reported by the MO Department of Natural Resources about the collection of the UCO in the MO State recycling program reports are aggregate date. The 2015 reports have reported a 35,360 l of UCO recycled per year but any other information has been founded about the management and strategy to implement the collection quantities of UCO.

In MO on 114 counties, four are having a recycling drop-off where UCO is accepted like a solid waste but it remains a local-municipal service.

To quantify the MO potential UCO (UCO_M) collection, the method used for the S1 baseline was taken into account considering six metro areas.

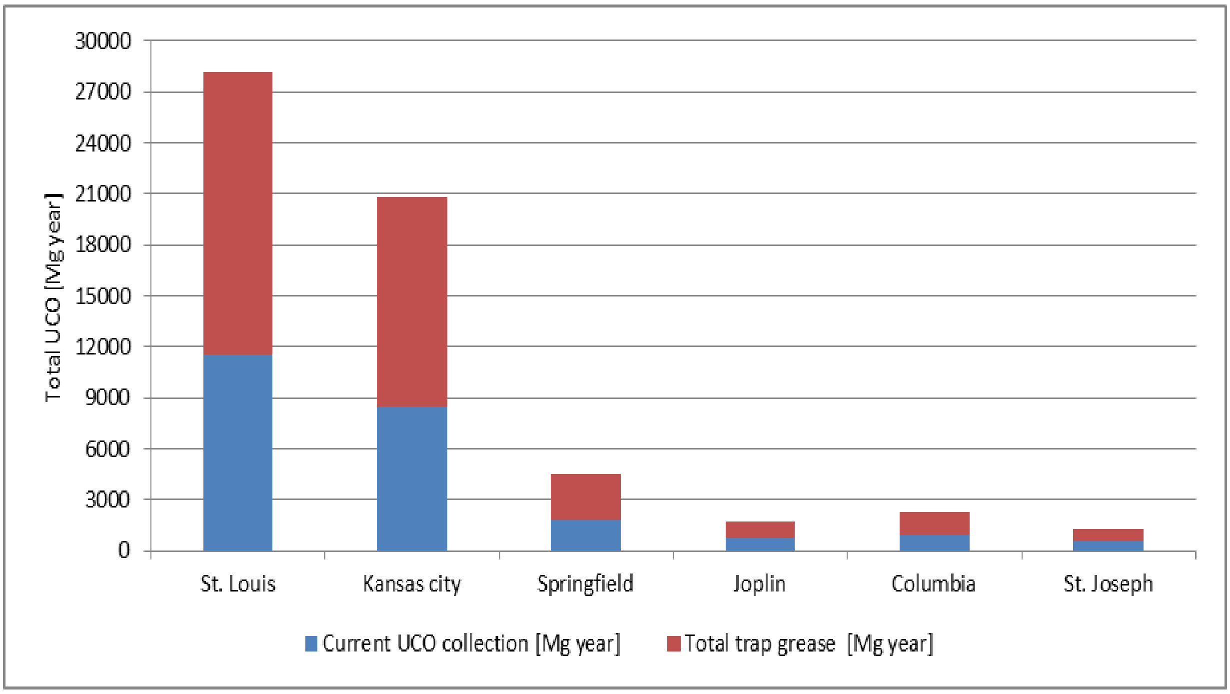

Figure 9. UCO and grease potential collection in the S2 best case

Table 9

Missouri Overview UCO quantities results.

Source: Author's elaboration.

Tot. UCO case study area	**Quantities**
UCO_C [Mg year]	$2.23 \cdot 10^3$
UCO_{Cpg} [Mg year]	$7.47 \cdot 10^3$
UCO_{MO} [Mg year]	$5.88 \cdot 10^4$

3.8 Benefits and output evaluation

3.8.1 Emilia Romagna

Results suggest that the introduction of UCO on the feeding mix of the biogas plants could lead to land saving up to 30% in the S1 Intermediate scenario and 43% in the best case scenario. In the baseline scenario were the UCO is not used, 728.36 hectares per year are used to supply the total corn need to feed the four biogas plant. The land saved in the S1 scenario is about 210 hectares per year and 409 in the best case scenario.

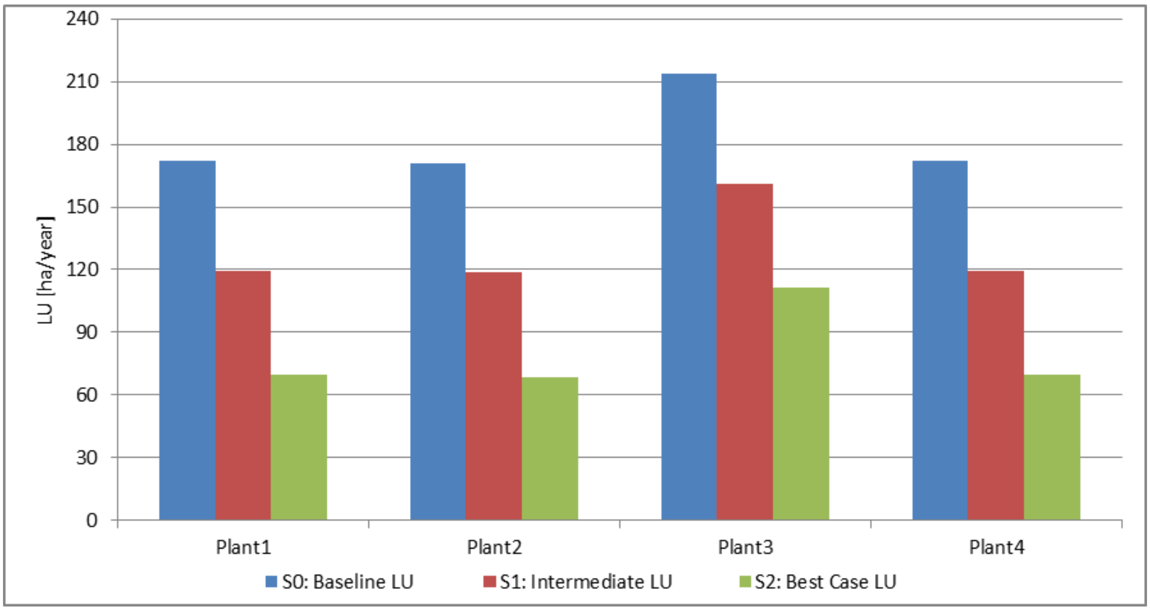

Figure 10. Land use and land save results overview

Land saved with the UCO introduction in the biogas plant diet is not the only positive results. The BMP value of UCO is higher than the BMP of the corn and this could also increase the methane potential.

Table 10

Emilia Romagna Overview results focus on land use (LU) and land save (LS).

Source: Author's elaboration

	Scenarios		
Year 2016*Total plants	S0: Baseline	S1: Intermediate	S2: Best Case
T_{CORN} [Mg year]	$4.01 \cdot 10^4$	$3.90 \cdot 10^4$	$3.80 \cdot 10^4$
Methane [Nm^3CH_4/Mg^{-1} SV]	$1.14 \cdot 10^6$	$1.95 \cdot 10^6$	$2.72 \cdot 10^6$
UCO collected [Mg^{-1}/year]	0.00	$1.03 \cdot 10^3$	$2.01 \cdot 10^3$
LU [ha/year]	$7.28 \cdot 10^2$	$5.19 \cdot 10^2$	$3.19 \cdot 10^2$
LU [ha/day]	2.00	1.42	0.87
LS [ha/year]	0.00	$2.10 \cdot 10^2$	$4.10 \cdot 10^2$
LS [ha/day]	0.00	0.57	1.12

3.7.2 Missouri

The UCO use for energy production in a biofuel facility could be explained in two different ways. The first way is a co-operation in feedstock with soy oil and UCO oil to better stimulate the multiple feedstock use. Moreover, to address the UCO in a biodiesel facility, were the technologies are available, use the UCO could answer to the City waste management how to dispose this polluting matrix. Another way to explain the data results is in terms of land use and lands save. The facility could makes a different choice introducing UCO that have no impact on land use this because is a waste and already liquid.

With the Introduction of UCO_C in a biodiesel plant, an average increase of biofuel production can be registered of around 1.33% . This quantities increase also with the co-operation with the UCO_{Cpg} of plus 4.45% and a 35.07% with the UCO_M.

Table 10 also shows that currently no land save is adopted. Introducing the UCO_C quantities on 308108.20 hectares per year used by the biodiesel facilities, 4100.66 could be saved and this amount increase with the introduction of UCOM quantity to 200049.47 hectares per year. The population growth in Columbia has been taken into account also because is a City with that registered a constant population growth in the last 16 years. From the year 2000 to the year 2016, the average population growth has been about the 3.35%. It was supposed that the same growth in population could be registered.

Table 11

Missouri overview results focus on land use (LU) and land save (LS).

Source: Author's elaboration

Biodiesel Plant					
Current Biodiesel Production [Mg year]			**Current land use [ha year]**		
$1.68 \cdot 10^5$			$2.69 \cdot 10^5$		
Co-operation in production			**Co-operation in land save**		
UCO_C [Mg year]	**UCO_{Cpg}** [Mg year]	**UCO_M** [Mg year]	**UCO_C** [ha year]	**UCO_{Cpg}** [ha year]	**UCO_M** [ha year]
$2.23 \cdot 10^3$	$7.47 \cdot 10^3$	$5.88 \cdot 10^4$	$3.58 \cdot 10^3$	$1.20 \cdot 10^4$	$9.43 \cdot 10^4$
Biodiesel + UCO_C	**Biodiesel + UCO_{Cpg}**	**Biodiesel + UCO_M**	**Land use – UCO_C** [Mha year]	**Land use - $UCOC_{Pg}$** [ha year]	**Land use – UCO_M** [ha year]
$1.70 \cdot 10^5$	$1.75 \cdot 10^5$	$2.23 \cdot 10^5$	$2.65 \cdot 10^5$	$2.57 \cdot 10^5$	$1.75 \cdot 10^5$

3.5. SWOT and comparative analysis

3.5.1 SWOT analysis S0 baseline ER and MO

Strengths	**Weaknesses**
Abundance of natural resources and by-products Regional power on administrative and decision planning for energy policy Agricultural diversification and developed agro-business sector Farm-base individual or cooperative structure Ambitious EU targets for renewable energy production Ambitious EU targets for renewable energy production CONOE monitoring and support to the entire UCO supply chain Traceability **Opportunities** Upgrading system for biogas plant after 20 years and technological development By-products supply chain enforcement with the 70 km supply chain Reduction of waste for landfill New research and studies on UCO in co-digestion for methane production Local energy system creation	By-products availability doesn't meet the biogas plant demand Policy tools to develop the biogas system are not design taking account the regional biomass Equal incentives for biomass, the incentives are calculated on the electricity production and not on the input. No standard collection UCO system Uncertainty about the 70 km area like short supply chain Geographical barrier for feedstock supply **Threats** Italian governance system to be slow to create a new regulation and stimulate the policy Bureaucracy and limited trust in the political system especially for waste management Disparity for already constructed plants and failure of the sustainability of the biogas system without incentives Weak concern about environmental EU changing in waste definition

Strengths	**Weaknesses**
Abundance of natural resources and biomass With a voluntary RES each state can take into account their specific features Market oriented and not linked with incentives tools support Private partnership biofuel facility structure Advanced biofuel target recognize the UCO and animal fats like a resources and not a waste and increased the consumption biofuel Competition in the market that can stimulate the technology development	Centralized energy policy for biofuel Federal and political position influence the national government to better low design Less agricultural manufacturing income to by-product use in energy production Animal fats compete with UCO for biodiesel feedstock No standard UCO collection Weak communication between at locate to national level Weak targets for electricity production by renewable sources Geographical distance Distance from the private UCO collection company and city waste management Feedstock have to come from 80% MO, if UCO is a feedstock this could limited the

	efficient disposal especially because the biggest city that are located on the border can't cooperated
Strengths Abundance of natural resources and biomass With a voluntary RES each state can take into account their specific features Market oriented and not linked with incentives tools support Private partnership biofuel facility structure Advanced biofuel target recognize the UCO and animal fats like a resources and not a waste and increased the consumption biofuel Competition in the market that can stimulate the technology development	**Threats** Market oriented can give less attention to environmental benefits Concern about cheap energy fuel lobby Incentives to oil company Consumption is voluntary and this follow the energy market price No obligation for fuel station to sell biodiesel No population growth

3.5.2 Comparative analysis S0

In the baseline scenario in the both cases the strengths are the abundance of natural resources and biomass availability and by-products suitable for bioenergy production. Moreover in the both cases at the local, regional and national level, the EU or Federal decision, affected the case studies investment in different bioenergy sector and there is not a standard UCO collection. Nevertheless, the two case studies show some important difference.

In ER the biogas plants are mostly farm-based individual or cooperative businesses and the national consortium C.O.N.O.E. makes a significant role to monitoring and stimulate the UCO supply chain. Especially for electricity production from renewable sources, the ambitious EU targets are continuously stimulating the regional sustainability standard for biomass production and to pursue the renewable energy goal.

Differently in MO where the biofuel facilities are a private partnership with a market oriented approaches. The ambitious federal standard is mostly for biofuel and renewable electricity follow the voluntary assumption. This point is a strengths in MO, because to produce electricity from renewable sources in a voluntary way without public incentives, makes a cost efficient. Moreover each state can design the better policy taking into account the specific territorial features. At federal level the ambitious targets for biofuel mandatory consumption and the introduction in the Renewable Fuel Standard 2 of the advanced biofuel category, developed a market for UCO.

Generally the strengths of the ER case are weaknesses in MO.

ER have such a small territory with high density in population that makes easier for the private companies collects the UCO decreasing the transport impacts. The short supply chain concept defined like sustainable way to procure biomass could also be a weakness to limits the geographic by-products availability.

In Contrast MO is low populated area were distance and geographical position could be a natural barrier for a short supply chain development equal to an ER concept. Also the income from agribusiness is not comparable with the ER incomes with a less concern about food manufacturing and by-product valorization. Also in MO the territorial biomass limitation could restrict the biomass availability especially for the UCO. In MO the biggest city are located at the border and if the biomass from biodiesel facility have to come from the MO state that can limited the cooperation between the biggest cities. But at the same time, applying a short supply chain for the UCO waste valorization can be an opportunity to develop new small facility that could run with the UCO and give environmental benefits in terms of land, transportation and waste water management for the city of Columbia in this case.

The threats for ER case study are more related with the political and individual concern about environmental aspect connected with the UCO and the amount of bureaucracy and slow political work also if there is EU policy and structured tools to develop it.

In MO there is a weak concern on environmental aspect and the consumption issues especially for biofuel is not mandatory at all and oil company and Coal Company makes a lobby work.

3.5.3. SWOT analysis S1 Intermediary ER and MO

Strengths	**Weaknesses**
Biogas plants quite near the biggest cities Collaborative system between local and regional	No biodiesel or bio liquid plant in the area Not enough information about the digestate characteristics in case of UCO use

Efficiency in land reduction Small area with high population density Normative obligation for the UCO producers to recycle it Abundance of UCO collection drop-off **Opportunities** Local expertise For future biome than plants More plant load diversification Circular economy New supply creation Power resources that can be stored and used in a seasonality less corn Create a new supply chain with a market price competition	The domestic collection system is voluntary **Threats** Waste definition

Strengths	**Weaknesses**
The biodiesel plant is quite near to Columbia city with a high technical and research groups The biodiesel plant have power and expertise The city are well connected The small quantity of the UCO doesn't compete with the soy oil Environmental benefits in terms of land save and all what is related to land Use local expertise **Opportunities** Local expertise Could stimulate the Columbia local authority to enhance the public waste management SSC could be start to be applies also for food where the concern is less power than ER Creation incentives for a feedstock that already have a market	Hard to understand which is the connection in the market between supply and demand of UCO There is not a consortium that can assist in company creation and supply construction and enforcement Is a small quantity for this enormous facility Less population in comparison with the two biggest city at the border of MO **Threats** Institution apathy to recycle UCO Cost effective and scale economy Private company more attractive for biggest city

3.5.4 Comparative analysis S1

In both cases the strengths are basically connected with the case study area research in terms of distance, transportation, facility technology knowledge and local resource use. Furthermore in terms of land and all benefits that could be connected with the land conservation, represents a benefit but also a great opportunities for both case studies. In the S1 case study also the weakness are mostly the same related with the available information, data analysis methods and the domestically waste management system. Also if the opportunities are mostly the same to create and stimulate a circular economy for more local resources, the most different in the opportunity is related with what supply chain means.

In Emilia Romagna a new supply chain for UCO for biogas or methane production, could give to the UCO a new market price and bee more cost-available. In MO, where a geographical limit already exist for biofuel production, the UCO already have a convenient price and the supply chain could be empowered and enriched with the short supply chain concept also for other kind of a waste, biomass or food.

In terms of threats in Emilia Romagna results necessary a changing in the EU definition of waste and give to the UCO a new value like a source. In MO are related with Cost effective and economy scale and the apathy of the public institution to work it out collaborating with private company.

3.5.5. SWOT analysis S2 Best Case

Strengths	**Weaknesses**
Significant land use reduction for a small scale area Land saved from energy crops and monoculture intense production for a more biodiversity land value **Opportunities** Land reached in biodiversity has a different value of soil erosion land by monoculture. Land market could increase the land value that makes the triple benefits for the farmer. Move on in a way of zero waste Circular economy development	Slow policy implementation at local level No information about Mordano collection system **Threats** Oligopoly energy market Weak link between the society industry and research sector

Strengths	**Weaknesses**
Significant Land use reduction Land save for more biodiversity and less soil erosion in a monoculture agricultural system Respect of the principle to use biomass coming from MO	Less concern if there isn't a economic value Little capacity of public institution to include civil society Little capacity from private sector to communicate with local society

	Slow power in policy implementation at local level Weak concern at the management system and bioenergy in general
Opportunities Creation an environmental economic value for land rich in biodiversity Use of national expertise	**Threats** Lobby work on the public sector Carbon and oil lobby Not unique definition in what is renewable and limits to biomass resources

3.5.6. Comparative analysis

In the S2 case study in ER and MO, a significant land reduction could be registered. Moreover less land is used for energy crops with intense monoculture system production, more land could be saved and be managed in a different way. Land represents high value resources in both cases because ER is a semi-rural area and MO completely rural.

On the total agricultural land available in each case study, both address the same amount to crop production. In MO the biggest differences is that there are not social sustainable standard so land can play an important role for the future generation food and a way to manage it and save it from soil erosion should be done. At the same time in both cases where the agricultural sector direction is an old people and centralizing the production in less big farm, creating a new value for biodiversity land could also attract small entrepreneur that intend to diversity the production or produce in a more ecological way. Weakness is most the same put change the scale. In ER no information about why the Mordano registered a high performance in collection. In MO State why there are some areas more concern that other.

4. Conclusion and policy implication

The substitution of ECs with used cooking oil could have a great effect in the two case studies analyzed in terms of agricultural land save. The feasibility to enhance the UCO collection and use in a short supply chain depends on several factors and need policy interventions.

The factors that can affect this policy can be summarized in endogenous factor like federal and EU targets, farm organization, geographical features and public-private relationship, UCO waste management and been a producers or consumer of energy makes the two case studies in a different position. Furthermore exogenous factors also affect the possibility to stimulate the short supply chain of UCO to use in bioenergy system. These are the concern about environment output, land management, social and sustainability standards and use of the resources as local as possible.

The first consideration is about the short supply chain principle and the 70 Km diameter. Specifically the weakness is connected with the method used to establish this geographical restriction in biomass availability, what is a sustainable area, what is local. Moreover the short supply chain that is well implemented in Emilia Romagna region for local food consumption could be used also for waste but a clear definition of what is waste or resources should be considered.

The use of land puts pressure on the availability of land and therefore contributes to future land use change so the short supply chain can also be an opportunity for both case studies to developed and implemented their specific sustainable standards environmental benefits.

The bioenergy in general and UCO collection could give environmental benefits and but in MO that is mostly a system regulated by market, the environmental concern could passed by the economic profit where cheap energy and cost-effective energy system dominate the public debate. The environmental benefits and economic feasibility should do go together and a more public intervention of renewable energy development in general could increase the awareness about it and resolve the market failure.

Moreover the UCO market is a young market for both and a start point to stimulate the interest in what the case studies already have, or could have to reuse in bioenergy system production is necessary. Land use play also an important rule and the agronomic choise in what to produce and how makes the case studies different in bioenergy development. Agricultural diversification, farm size and available land makes the ER an agricultural producers in biogas to reuse the several by-products that didn’t had a market before it. A different agricultural choice was make under the federal policy to be energy independent especially from oil. Intense monoculture of corn and soybeans characterized the MO and were a biogas technology for several materials couldn’t be proficient like a biodiesel plant in Emilia Romagna with the same size of the MO one. Also opportunity in both case could be the same but rewritten what is local.

Also, if the social, economic and environmental benefits for producing energy from waste are well recognized, then current policies which focus on planning and regulation that contain subsidies don’t necessarily focus on the SSC, but should be used to better stimulate the use of all the resources as locally as possible.

Through the SSC several benefits could be registered like diversification and integration of agricultural income sector and the opportunity to create new business, increase market and economic value of by-product and stimulate technologies to enlarge the list of product that could be used for energy production.

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Conclusions

Technical and Economic feasibility

Used cooking oil (UCO) can be considered either a waste product with negative effects on the environment or a resource if contributing to energy production. This thesis investigated the technical feasibility of integrating UCO into two bioenergy systems: anaerobic digestion (AD) for biogas production and transesterification process for biodiesel production. The work demonstrated the technical and economic feasibility of the substitution of energy crops with UCO. UCO is characterized by around 99% of volatile solid (VS) and the methane potential is around 10.12 times higher that corn. This demonstrates the efficient conversion yield from corn to UCO for methane production and the opportunity for the entire system to introduce in the biogas plant a lower amount of matter with higher yield than corn. UCO efficiency makes it also profitable for the biogas entrepreneurs. With market price around €490 per Mg, fewer quantities of corns need to produce the same amount of biogas with a positive overall feedstock costs reduction for the biogas load. Moreover a new allocation would lead to a reduction of the price paid by recovery companies to regenerate it and would stimulate the growth of the collectible quantity. For the biofuel sector, a value of about 94% of yield conversion of UCO to biodiesel from soy oil has been considered. This feature makes UCO an efficient matrix to be utilized in both energy systems.

Agricultural Land Use

In the Emilia Romagna case study results suggest that the introduction of UCO on the feeding mix of the biogas plants could lead to land saving ranging from 30% to 43%. However, due to the current legislative framework, that defines UCO simply as waste, the use of UCO is not recognized as contributing neither to direct or indirect land use change. For the biodiesel plant land saving range from 1.33% to 35.07% with the higher value corresponding to an amount of 94.261 hectare per year.

The use of UCO would allow maintaining a stable production of energy along the year, mitigating the environmental impact, and ensuring economic benefits for farmers.

Land availability represents a crucial factor in the strategic decisions on land use (what and how to produce). This is emphasized in the two case studies. In Emilia Romagna policy developments shifted from the support to energy crops as maize to the introduction of limits and to the promotion of agricultural by-products to improve land management and reduce the pressure on land use. In Missouri, due to the large availability of land, no major constrains to the intensive production systems where posed. As expected resource scarcity create a pressure to more sustainable strategies.

Policy Implication

The partial substitution of ECs with UCO is technically feasible and economically viable with a major constraint put in place by the current legislative framework that limits the collection and the utilization of UCO for anaerobic digestion. Policy interventions should be aimed at removing the barriers that currently limit UCO collection and reuse in biogas and biofuel energy systems.

The barriers that can affect the UCO valorization in two different bioenergy systems can be summarized in:

- endogenous factors like federal and EU renewable energy targets, farm organization and dimension, geographical features, public-private relationship and UCO waste management;
- exogenous factors that affect the possibility to stimulate UCO disposal as the environmental implications and economic output, land management in a long term prospective, social and sustainability standards, a common method for waste and resource definition, a common methodology to evaluate how the transport and geographic limit for biomass availability can enhance the short supply chain rather that limiting the availability of the resource.

Policy interventions should focus also on the creation of public-private relationship aimed at facilitating UCO collection and disposal and on awareness rising to inform food chain stakeholders about the economic and environmental benefits of the integration of UCO in bioenergy systems.

Also, if the social, economic and environmental benefits for producing energy from waste are widely acknowledged, then, policies interventions should recognize the role of endogenous resources promoting their valorization. In this sense the comparative analysis pose a question on the definition and on the sustainability of the concept of short supply chain that should be addressed by taking into consideration logistical and geographical barriers, and - as anticipated - the availability of local resources. The development of energy short supply chains could ensure the distribution of benefits to local communities by stimulating the diversification of agricultural income, the promotion of new business opportunities, the identification of the economic value of by-products, and the creation of a demand for new technologies to enlarge the list of product that could be used for energy production.

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