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Placement optimization of biodiesel production plant by means of centroid mathematical method

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Abstract

The uncertainty about the world energy production, the lack of crude oil reserves, the environmental problems caused by a massive use of fossil fuels and their increased prices, are the main reasons inducing modern society to find alternative solutions for fuels production. According to this point of view, a great attention is addressed to the biodiesel production as substitute of diesel derived by fossil hydrocarbons. The use of biomasses from different sources for the energy production constitutes one of the main objects thanks to which European Community intends to reduce its dependence from oil importations and derived products over the medium to longer term. Several sources can be used for biodiesel production, among these *Brassica carinata* and *Brassica napus* are considered as possible dedicated energy crops. The present work is based on the implementation of a model that allows to analyze the insertion of agro-energetic farms, identifying and evaluating the crops previously mentioned, economically suitable to enter in rotation with cereals and legumes. Through the analysis of official statistical data and cereals and legumes production, an estimation of potential biodiesel production in relation with the considered territory chosen as case study. It was implemented a model based on a procedure of logistics and distribution management in Matlab and in a Gis environment in order to find the best location for a potential production plant. The model considered some collection points of crops according the administrative units of the territory of reference. Moreover, for the same territory, thanks to some simulations it was calculated how the potential biodiesel production could affect fuels consumption and the potential reduction of the amount of CO_2 in the environment.

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1. Introduction

The uncertainty about the energy production in the world, the insufficient reserves of oil, the environmental consequences of the massive use of fossil fuels and their increasing prices, are the main reasons that induce the modern community to find alternative solutions to the use of oil [1]. In this context, many renewable energy sources have been investigated and, among them, a great attention is turned to the production of biodiesel as substitute of diesel derived by fossil hydrocarbons [2]. The energy produced with biomasses and in particularly by the combustion of biodiesel is considered a clean energy thanks to their low emission pollutants, and above all, the zero balance of carbon dioxide [3]. The CO_2 emitted during the combustion of biodiesel is the same that was absorbed during the growth of the plants whereby it was produced annulling in this way the overall calculation. This not means that the use of biodiesel does not involve CO_2 emissions but only that the CO_2 generated by the combustion is renewable at 95% while the remaining 5%, due to not biogenic components, is not renewable. Nevertheless, there are some problems referring to the cultivation of plants which raw material is extracting from. What mentioned above would assume a social value if the raw material for the production of biodiesel was cultivated in barren wastelands or deserts, but as it often happens, the cultivation takes the place of another that already contributes to absorb carbon dioxide from atmosphere [4]. The production processes described above could easily be integrated with energy plants necessary for the same process, by using renewable sources such as wind power plants [5,6] or photovoltaic plants [7,8]. This makes the whole biodiesel production process clean and with zero or near zero greenhouse gases emissions. Therefore this source is particularly attractive for the promotion of the environmental sustainability [9] directly applicable as solution for the current problems of air pollutions [10,11, 12] caused by mobility in urban areas [13,14]. The use of biomasses from several sources for the energy production constitutes one of the keys thanks to which European community means to reduce its dependence from imported oils and derived products in middle and long term. In application of the Directive 2009/28/CE about renewable energies promotion, each State has to reach some goals within 2020, in particularly about transports, the quote of consumptions from renewable sources has to get at least 10% of the total consumption. According to [15] considering the current state of the technical development of the use of renewable sources in transports, this goal could be reach only through a massive use of biofuels. Several crops could be used for the energy production: the agrarian cultivations normally used for alimentation, sugar crops, industrial crops, the forestall biomasses and some marine biomasses (seaweeds). Nevertheless, it is possible to increase the production of “dedicated cultivations”. Among these crops the *Brassica carinata* and *Brassica napus* [7] deserve a great attention. The use of cultivations for energy production implies a verification of the accumulated and used energy in the production processes, because obviously only the crops whose energy balance is positive are adapted for this porpoise [16].

The present work focuses on the development of a model able to analyze and find the best location in Sicily for a theoretical agro-energetic plant, identifying and evaluating energy cultures such as *Brassica carinata* and *Brassica napus*, economically convenient and suitable to be part of the crop rotation with Cereals and legumes [17, 18]. It was estimated the theoretical total production of biodiesel for the Sicilian provinces thanks to the last official statistical censuses about agriculture and specifically the production of cereals and legumes. The model is based on concepts of Distribution logistics and considering for each province the collection points it was calculate a theoretical best position for the biodiesel production plant in Sicily. It was also taken into account how the simulated production of biodiesel could affect to the fossil fouls consumption in Sicily and the amount of avoided CO_2.

2. Biodiesel environmental aspects

The biodiesel is a natural product usable as fuel for transports and heating fuel [19]. The minimum necessary requirements for the use of biodiesel as transports or heating fuel are indicated respectively in the norms UNI 10946 and UNI 10947. The use as an alternative to fossil fuels presents some important advantages in term of environmental sustainability. The CO_2 emissions are particularly low with a reduction of 78% respect to fossil diesels [20]. The emissions of particulate matters (PM_{10}) 68% less than those of fossil fuels and without any polycyclic aromatic hydrocarbons. Therefore the use of biodiesel does not contribute to the emissions of gases responsible to greenhouse effects because it gives back to atmosphere the same amount of CO_2 absorbed by crops during their growth. In any case it has to be considered that biofuels derived by cultivations are in competition with food production and, with the aim at avoiding discrepancies on productions, European community with the Directive 2015/1513 has established a maximum of 7% for the contribution of biofuels produced by food crops.

3. Suitable crops for biodiesel production

3.1. Brassicaceae

The *Brassicaceae* are a big family of grassy plants located in all continents and with any climate. The maximum center of biodiversity for this family, in terms of number of species, is the Mediterranean basin. *Brassicaceae* are characterized by not very deep tap roots. The trunk is erect and forked reaching usually an height of 1,5 m. The leaves are usually alternate, just in few cases opposite, often in basal rosette; the layer is often engraved or pinnate without stipules. The fruit that develops from the fertilized flower contains generally from 15 to 40 seeds depending on the variety. The seeds are small, smooth and spherical, the seed coat is usually around the 12-20 % of the total weight; a part of it the seed is composed by two cotyledons and the embryo. The embryo contains from 38% to 50% (the average is 40-42%) of oil and the 21-24% of proteins. There are several species of plants belonging to Brassicacee, among them *Brassica carinata* and *Brassica napus*.

3.2. Botanical characteristics of Brassica napus

In the Italian climate the biological cycle of *Brassica napus* is autumn-spring. It is usually planted between the end of September and the beginning of October and takes about two weeks to appear, it lasts to cold temperatures (up to – 15° C). After 30-40 days from the fecundation, the seeds start to fill of materials; the amount of oil gets the maximum value after around 60 days. The *Brassica napus* does not need of high temperatures to develop. It adapts itself to clay, calcareous and peaty lands as long as drained. It is a yearly herbaceous plant that could be rotated with cereals and legumes.

3.3. Botanical characteristics of Brassica carinata

The *Brassica carinata* takes its origins from Eastern Africa. The cultivation of this species in Ethiopia has grown from about 40 years and has mainly spread in the uplands, between 2000 and 2700 m above sea level, where it seems to be able to provide 2,6/3,5 t/ha with the percentage of oil in the seeds ranging from 37 to 51%. Recently the cultivation of this species has aroused a considerable interest in other countries. The reasons of this interest seems to lay in its greater vigoria, productive potentialities and resistance to biotic and abiotic stresses. These characteristics make it adapted to stand to agro-climatic sub-optimal conditions. This hypothesis seems to be confirmed from recent studies conducted in Italy. According several test years, the yields varied from 1,89 t/ha to 3,02 t/ha with a percentage of seeds oil between 33% and 40%. The smallest variation of yields in different locations indicates a better adaptation of this species to typical Mediterranean environments, respect to *Brassica napus* [21].

4. Study Area

Sicily, the biggest island of Mediterranean sea, with a total surface of about 25.000 km2 extends in latitude from 36° to 38° North and in longitude 12° to 15° East. The orography varies consistently: the northern part is mainly mountainous, the center-southern is collinear; the eastern zone is volcanic while the rest of the island is characterized by the presence of plateaus. The variety of landscapes of Sicily does not allow to attribute an homogeneous climatic condition to the whole territory of the island. By considering the mean conditions of the territory, according to the Köppen macroclimatic classification, it could be defined a region of humid-temperate climate C type (the coldest month presents temperature in the range from -3°C to 18°C). The climate of the northern and eastern coasts is generally mild during the winter and hot during the summer with yearly means of 18 °C. The southern coasts and the inlands suffer mainly the influence of warm African winds with a torrid summer climate [22]. The inner mountainous areas present a colder climate, characterized by thermal excursions and frequent rainfalls during winter months. The rains of Sicily are not copious with general yearly means less than 700 mm, concentrated between the late autumn and the early spring. The southern and western parts are particularly dry and also some valleys of the inner zones isolated by mountains which limits the marine influences, where annual rainfalls are very low, less than 500 mm, while the African influences are very strong [23]. The Tyrrhenian and Ionian coasts of Sicily are more rainy with annual quantities exceeding 800 mm and can be greater than 1000 mm in correspondence of reliefs, where during the winter season there are usual heavy snowfalls. The predominant winds are Mistral and Sirocco, but the Libeccio is also frequent during the middle seasons and Tramontane in winter. These winds are responsible of the heavy rains and sudden collapses of temperatures. The predominant vegetation is Mediterranean characterized by Oaks, laurels, Arbutus and olives [24]. There are also tropical essences such as prickly pears, fat plants, palms, while with altitudes upper than 1000 m there are oaks, beeches, maples. Some areas particularly arid present typical aspects of the steppe with meadows characterized by an alternation of fat plants and evergreen shrubs.

5. Data collection and analysis

Thanks to ISTAT data of the last official agricultural census in Sicily (2010) and ISTAT data (2011) about the available lands for cultivation of cereals and legumes it was possible to obtain the used agricultural surface (SAU) and the production of legumes and cereals for all provinces of Sicily (PROD). These parameters were calculated according methodologies reported in [17,18]. Table 1 shows these data for all provinces:

Table 1. SAU and PROD for all Sicilian provinces

	AG	CL	CT	EN	ME	PA	RG	SR	TP
SAU_C [ha]	44575	39400	30990	53121	1630	92544	15050	16401	24000
SAU_L [ha]	4047	1650	1318	n.p.	330	330	130	122	850
SAU_{TOT} [ha]	48622	41050	32308	53121	1960	92874	15180	16523	24850
$PROD_C$ [t]	138402	107500	102485	106242	2900	272050	49575	40077,3	61000
$PROD_L$ [t]	7542,5	2875	2396	n.p.	302	719	161	234,4	1910
$PROD_{TOT}$ [t]	145944,5	110375	104881	106242	3202	272769	49736	40311,7	62910

The high production of cereals and legumes in Sicily allows to adopt the rotation of 1/3 of lands with energetic cultures ad hoc, such as *Brassicata Carinata* and *Brassicata Napus* that are conformed with the pedoclimatic Sicilian conditions [17,18]. In particular, *Brassica Napus* is more adapted to the inlands of the Sicilian territory while for the coastal zones *Brassica Carinata*. According data reported in Table 2 it was possible to obtain for each province the available agricultural surface for Biodiesel ($SAU_{biodiesel}$) according to [19]. It corresponds more or less to the 1/3 of SAU_{TOT} for each province as it was assumed a rotation of 1/3 of available lands. At a later stage the obtained $SAU_{Biodiesel}$ was multiplied for the agricultural yield in order to obtain the total production of cultivations. Considering that the embryo of *Brassicaceae* contains on average an amount of oil of about 40% of the total weight of the seed, the derived biodiesel production for all Sicilian provinces is equal to 40% of the production of cultures ad hoc. In table 2 the indices are reporterd:

Table 2. biodiesel indices for all Sicilian provinces.

Province	$SAU_{Biodiesel}$ [ha]	Agricultural yeld [t/ha]	Cultivations production[t]	Biodiesel production [t]
AG	16207,33	3,00	48621,98	19448,79
CL	13683,31	2,69	36808,11	14723,24
CT	10769,34	3,25	35000,35	14000,14
EN	17707,00	2,00	35414,00	14165,60
ME	653,36	1,63	1064,98	425,99
PA	30958,00	2,94	91016,52	36406,61
RG	5060,00	3,28	16596,80	6638,72
SR	5507,67	2,44	13438,71	5375,48
TP	8283,35	2,53	20956,87	8382,75

As it can be inferred by data from table 2, the total production of Biodiesel for Sicily, estimated in 2011, is around 119.000 tons. After obtaining an estimation of biodiesel production it was quantified the impact of it to the real consumption of diesel in Sicily during the reference year. Consulting ACI database it was possible to extrapolate the amount of diesel consumed in Sicily on 2011; this quantity is around 1.630.400 tons. Moreover, it was calculate the ratio between the potential biodiesel production in Sicily and the real consumption of diesel for the considered year. This led to obtain the effect of the biodiesel production on diesel. This effect for 2011 is about 7,3 % implicating a reduction of CO_2 emissions to atmosphere of 370911,4 tons.

6. Methods and application

In order to obtain a best location for the possible plant for the biodiesel It was implemented a model based on a procedure of logistics and distribution management in Matlab and in a Gis environment (Fig. 1).

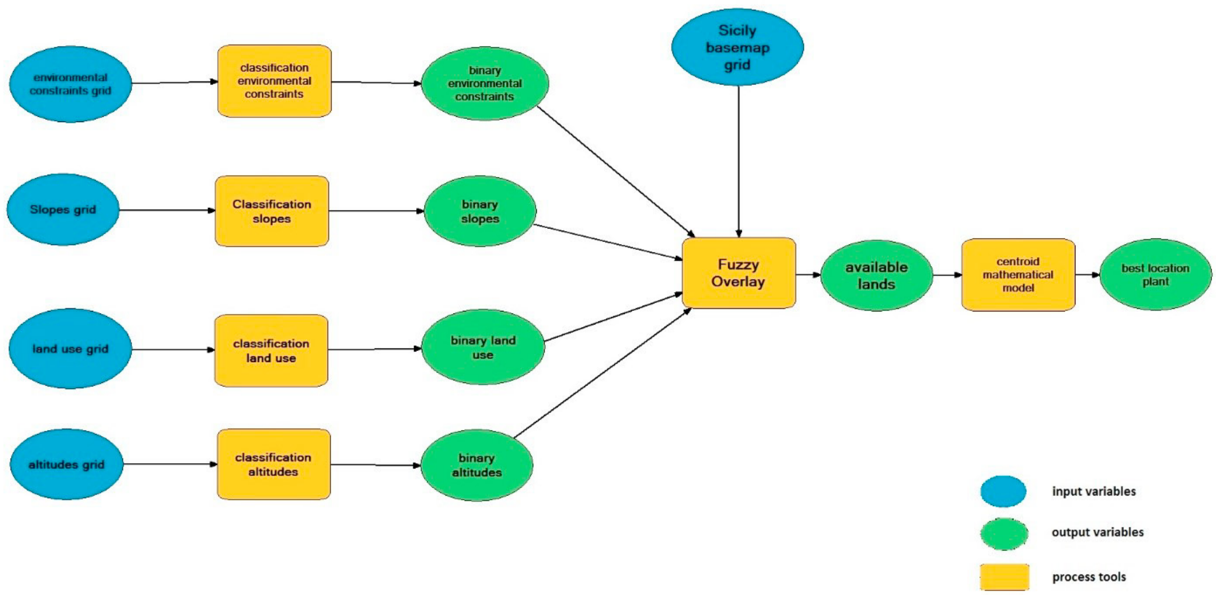

Fig. 1.The model flow diagram.

At the beginning the case study territory was analyzed in a GIS environment in order to identify those geographical constraints that were determinant for the plant location. Different raster layers such as land use grid, natural reserves grid, altitudes grid, slope grid, were combined according a fuzzy operation (combination of AND Boolean operators) in order to exclude those areas not suitable for the possible location. The main criteria are shown in table 3.

Table 3. Criteria for suitable lands.

Constraints	Criterion	Notes
Land use	exclusion	There were excluded all private, agricultural and urban lands.
Slope	S< 5%	Suitable pedoclimatic conditions for lands with a Slope < 5 %.
Altitudes	A < 500 [m] a.s.l	Suitable pedoclimatic conditions for lands at less than 500 m altitude.
Environmental constraints	exclusion	All natural reserves excluded .

The result was a binary grid of suitable/not suitable land areas shown in Fig. 2.

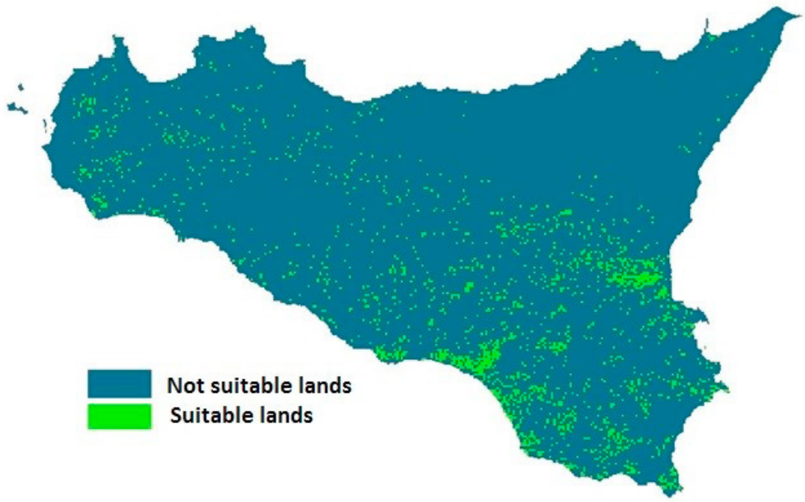

Fig. 2.The map of suitable/not suitable lands.

Once obtained these grid it was implemented in matlab a tool based on the centroid mathematical method to find the best location. This method was based on the idea of minimizing the transport costs from the storehouses of cultures to the biodiesel production plant. Given the coordinates (Xi, Yi) of the origin points (inbound flows) and destination points (outbound flows), considering for each point the annual flow (Qi) and the unitary transport cost (Ri) for unitary weight and distance and considering the distance (di) of the points from the center of gravity it was possible to calculate the center of gravity of these flow by minimizing the function “transport cost”:

$$\min \text{(Transport Cost)} = \min \textstyle\sum_i [Qi, Ri, di(x, y)] \quad (1)$$

This is an iterative method to calculate the position of the centroid. Each step the coordinates of the centroid (X*, Y*) are calculating according (2).

$$X^* = \frac{\sum_i \frac{Q_i \cdot R_i \cdot X_i}{d_i}}{\sum_i \frac{Q_i \cdot R_i}{d_i}} \qquad Y^* = \frac{\sum_i \frac{Q_i \cdot R_i \cdot Y_i}{d_i}}{\sum_i \frac{Q_i \cdot R_i}{d_i}} \tag{2}$$

The step later the distances d_i are recalculated and so the new coordinates of the centroid. The method was stopped when the difference between the calculated coordinates and the coordinates of first approximation was considered negligible (< 0,05 %).

There are some important assumptions in this method that has to be considered:

- The result is independent from the choice of the origin (0,0) of the reference system;
- It is better to consider R_i constant independently from the considered route (R_i=1 ∀ i);
- The result gives the coordinates of the center in a continuous space;
- This method is near/real time but does not consider several variables such as making costs or lands constraints.

7. Model result

In order to obtain a compromise between accuracy and model time consuming there were assumed some simplifications:

- There were calculated Euclidean distances as d_i;
- It was conceived that for each province there was a collection point for cultures corresponding to the capital of the province itself.
- There were considered As inbound/outbound flows those $PROD_{TOT}$ calculated in Table 1.
- It was used the international UTM coordinates system (expressed in m) and the datum WGS84 as reference system.

According these assumptions the model gave the result shown in Fig. 3. The coordinates of the last approximation of the best location correspond to the city called Villarosa in province of Enna. Its location allows to reach easily the motorway A19 (Catania-Palermo) thanks to the SS121 road.

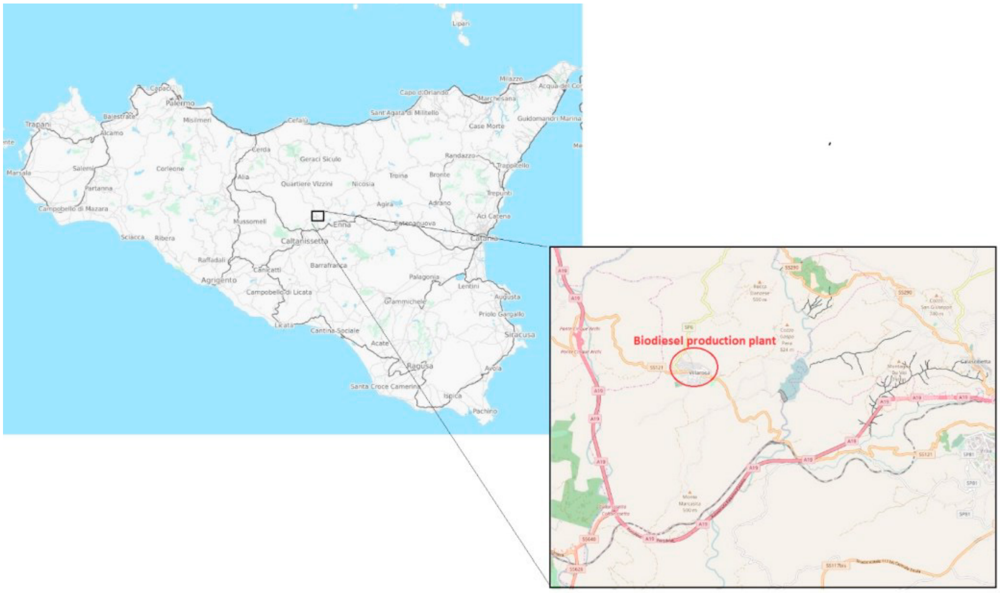

Fig. 3 The map of the model result.

8. Conclusions

The present paper is based on the implementation of a model that allows to find the best location of an agro-energetic farm in the territory of Sicily. The considered territory offers good prospects given that its high production of biomasses such as *Brassicaceae* family plants. The model was based of the theory of centroid mathematical method in combination with the use of GIS to consider some important geographical constraints. The combination with geographical patters such as land use, slopes, altitudes were determinant to find the best place. This model gave a good result in terms of time consuming and precision and it could be adapted by governing institutions in the decision-making processes in planning applications. For future work it is under investigation the opportunity to make the model more precise by considering more sophisticated transport systems and other geographical constraints.

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