Multi-scale integrated assessment of second generation bioethanol for transport sector in the Campania Region.

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Abstract

Current narrative on biofuels is backed up by a large number of studies published in the scientific literature that address second-generation bioethanol only through a single topic approach, nonetheless in the vast majority of cases transition to this energy carrier is evaluated as a generally 'promising' technology. This paper presents a first attempt in proposing an integrated evaluation of the actual benefits expected from bioethanol in the transport sector, by applying the Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM) to the prospective realization of a local system of bio-refinery in Campania Region (Southern Italy). MuSIASEM is a multi-criteria analysis enabling to deal with the complexity of a territorial energy system. Since the unavoidable intrinsic uncertainty, the study does not focus on predictions, but adopts a strategy of Quantitative Story-Telling about some relevant results underlying the limits and critical issues about the energy converter fabric, the economic profitability, environmental constraints and the questionable concept of marginal land. The findings suggest concluding toward falsification of key points in the current narrative: (i) the system is not an efficient solar energy converter; (ii) it fails to realize many of the expectations for a renewable energy carrier producer; (iii) the contribution to decarbonization strategies is not as high as desired and other environmental impacts could not be neglected; (iv) the very large land requirement is hardly compatible with conversion of truly marginal land in Campania region; (v) compared to alternate land uses it does not seem an actually promising strategy to regain value from rural economy.

Highlights

- Single topic studies are not useful for comprehension of a territorial biorefinery
- Multi-scale and multi-dimensional approach to face the ambiguity of energy concept
- Performance's comparison of two distinct energy production systems is misleading
- Decarbonization and marginal lands concepts are a simplification of the problem

Key words Second generation bioethanol; MuSIASEM; Energy converter; Marginal lands; Economic profit

1. Introduction

The adjective "promising" is extensively used in scientific literature as well as in stakeholders' lexicon with reference to second generation biofuels. Such biofuels begin to arouse interest, in the technological and political scene, after the failure of the first generation biofuels (Giampietro and Mayumi, 2009; Gomiero, 2015). Gomiero's (2015) exhaustive review explains very well the theoretical and practical development of the first generation biofuels towards second generation, based on the need to avoid conflicts in the use of the land between food production and production of energy carriers. Enthusiasm towards this fuel is reflected in European supporting policies as witnessed by the EU (Directive 2009/28/EC), posing the objective to achieve a share of 20% from renewable sources in 2020 in the consumed energy mix. Italy has recently adopted a decree (DM Sviluppo Economico [a]) to mandate the use of biofuels as substitute for gasoline and diesel according to the specific scheduling, together with administrative sanctions to comply with the above stated targets (DM Sviluppo Economico [b]).

Summarizing the prolific literature that has been produced over the last two decades on the subject, mainly based on single topic studies, and the stake-holders discourse, we can identify the following crucial points, characterizing the narrative in supporting biofuels. It involves environmental and socio-economic motivations: (i) biofuels are promising renewable sources for decarbonization strategies; (ii) biofuels can reduce fossil fuel dependency; (iii) biofuels can improve local marginal economies through the adoption of new technologies making it possible to revaluate marginal lands. The concept of "marginal lands" represents a key topic in the narrative, because it is assumed to have normative applications in redressing concerns regarding the food versus fuel question and it makes possible to say that there is no conflict over land use. In any case the concept remains elusive and not precisely known as an operational concept that can be applied and understood from a multi-scalar perspective. It is not uncommon in studies discussing the energy potentials of various agrofuel crops for authors to acknowledge food security concerns by making a passing statement that only marginal or degraded lands should be used for biomass cultivation without explicitly defining the term (Nalepa e Bauer, 2012). Historically, the concept of marginal land is associated with biophysical degradation caused by land misuse and/or overuse and consequent economic effects. This is largely determined by the territorial biophysical characteristics such as soil profile, temperature, rainfall and topography. For example, the project for which this study was carried out (see later) contemplates marginal lands as a promising solution for the bioenergy industry as an alternative to overused grain cropland for feedstock supply that could help to address the food vs. fuel debate challenging the industry's further development.

Currently, sustainability assessment of second generation bioethanol is pervasively approached by comparing its environmental performance with fossil counterpart by means of LCA (Life Cycle Assessment). This approach conceives the bioethanol as an energy carrier, with a defined production chain, to be compared with other energy carrier with the same function but different metabolic identity. Moreover, the comparison of the environmental performance is mainly focused on climate change saving, an obvious winner for biofuels because fossil fuels generate a net increase in the carbon fossil sink while liquid fuels from biomass are assumed to be associated with closed carbon loops. Our opinion is that this comparative framework is not effective since it compares two different production systems using a set of indicators developed in terms of their relevance only for one of the two (the traditional fossil energy). A typical comparative analysis tends to be focused on energy and matter flow analysis (up-stream and down-stream) in the metabolic process (*what the system does and how the system transforms fluxes*). On the contrary when biomass production is considered it becomes important not only to understand the various flows of inputs and outputs (*what the system does and how the system transforms fluxes; what we are trying to produce?; how do we produce biofuel?*) but also to understand *what the system is*, *what the system is made of*, *where the system is located*, *what are the "expectations" – the benchmarks – in relation to the pace and density of flows*). Only by adding this additional information it becomes possible to evaluate: (i) the constraints imposed by the biophysical characteristics of the territory where the production system insists (feasibility in relation to processes outside human control); (ii) the constraints imposed by the technical and economic characteristics (viability in relation to processes under human control); (iii) the desirability of the substitution of fossil energy fuels with bioethanol. This multiple check is required because there are several factors to be considered in order to understand whether a bioethanol production system can replace in the short time gasoline in the high energivorous and worldwide growing transport sector. At the moment gasoline's performance is characterized by high power density, low economic costs, low requirement of human labour. Would it be possible to guarantee the same performance when producing bioethanol? When looking at the existing drivers of the requirement of liquid fuels for the transport sector data are not encouraging. The transport sector in EU countries, in the year 2014, contributed for the 33.2% of the gross consumption of energy, estimated in 1,600 million tonnes of oil equivalent (Eurostat statistics). According to the forecasts of the International Energy Outlook (EIA, 2011), world energy consumption is expected to increase by 53% between 2008 and 2035 (1.6% per year), stimulated in particular by the industrial and transport sector. When considering this expected major increase in the requirement it is essential to verify the possibility of scaling up the production of bioethanol to satisfy the energy demand of transport sector. This assessment is made difficult by the large doses of uncertainty associated with environmental and socio-economic scenarios. Therefore, rather than providing exact predictions about future scenarios in this paper we will adopt a strategy of Quantitative Story-Telling (Saltelli and Giampietro, 2017), considering the specific narrative of this case, to face the possibility to carrying out a quantitative analysis aimed at check the robustness of the narrative in relation to its feasibility, viability and desirability. Therefore, the aim of the quantitative analysis presented goes beyond the need to make accurate assessments, rather we are looking for insights or knowledge gaps in the scientific information used in the process of decision-making. This implies considering the required quantity of biofuel to be produced to power the transport sector and then look at possible constraints in terms of: (i) feasibility – i.e. the requirement of a large area of land for feedstock production due to the very low power density can translate in a constraint on the scale of the production. Moreover, the large disturbance to local terrestrial ecosystems will imply other type of environmental impacts beside emissions relevant for climate change effect; (ii) viability – i.e. the economic return on the investment with and without subsidies; (iii) social desirability – i.e. what is the advantage for the local employment taking also into account the opportunity cost associated with alternative scenarios of land use (e.g. agro-tourism). In general terms we have to consider the aspects that can be used to study the chances of survival of the bio-ethanol production systems (short *vs* long life expectancy) when competing with other energy supply systems in the process of decarbonization.

Among the several feedstocks tested for this purpose, Giant reed (*Arundo donax* L.) is a perennial crop considered most suitable in the Mediterranean environment thanks to its characteristics to tolerate a wide range of environmental stresses fairly good yields with low agronomic input and generally favourable effects on soil carbon storage (Forte et al., 2015; Zucaro et al., 2016). This paper uses a case study related to a specific territorial context (Campania Region), to test the potentiality of second generation bioethanol from giant reed. Is it a promising strategy for producing energy carrier for transport sector in the Campania Region? To this aim, the study presents an analytical approach aiming to enhance the current wide studies' spectrum of assessing the feasibility, viability and desirability of bioethanol production by applying an integrated assessment framed within the Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM) accounting method (Giampietro et al., 2014). MuSIASEM approach has been developed to provide an integrated assessment structured on a multi-criteria analysis capable of dealing with the complexity of energy systems as well as the inherent ambiguity associated with the concept of "energy" (Diaz-Maurin and Giampietro, 2013). This approach generates a multi-domain, multi-level and multi-scale analytical framework able to evaluate the pertinence of a metabolic system, both as diagnostic tool and scenario tool. The MuSIASEM method has not yet been applied for the analysis of biofuels, with the only exception of work published by Borzoni (2011) referred to the production of soybean biodiesel in Brazil, in order to enrich the discussion on the implications of fossil fuel substitution with biodiesel. This paper showed how the use of a parallel biophysical and economic reading at different scales can shed light on the consequences and sustainability of alternative options to oil. In the landscape of multicriteria approaches, generally characterized by semantically closed models, MuSIASEM offers the concept of multi-purpose grammars able to deal with complex dynamic systems. Grammars are semantically open because they can be adapted to specific situations and incorporate new relevant qualitative elements in the analysis.

2. Material and methods

2.1 Studied system

The study was carried out inside the activities of the "EnerbioChem project" (PON01_01966, 2012–2015) which was conceived to evaluate the prospective realization of a local bio-refinery (Campania Region, Southern Italy) to recover the economic profitability of the marginal lands (http://www.novamont.com/enerbiochem-il-progetto). Potential marginal area was recognized in hilly wheat belt, corresponding to almost 150,000 ha, coming up to the Appennino mountain chain ridge (Pindozzi et al., 2013). This wide territory, corresponding to 27% of the overall Campania's agricultural surface, was part of the project's narrative because of the reduced soil fertility and economic profitability. Giant reed crop was selected as useful lingo-cellulosic feedstock since considered a perennial crop able to protect soil from weather aggressiveness, to accumulate soil organic matter and characterized by low agronomic inputs (Fagnano et al., 2015). Long-term field trials (2003–2014) were arranged in the Centro Rotary (40_ 920N, 15_ 120E, 700 m a.s.l.), an experimental farm of University of Napoli Federico II. Feedstock conversion phase has considered a second generation biorefinery plant, based on an innovative patented pretreatment technology developed by Italian company (details in Zucaro et al, 2016). The plant's yearly operational capacity is of 450,000 dry t and 127ML of feedstock transformation and biofuel production, respectively. Fig. 1 shows the characterization of the territorial bioethanol production system (BioOH-PS) in relation to its context. More detailed information about the feedstock cultivation and transformation process can be obtained in Zucaro et al. (2016).

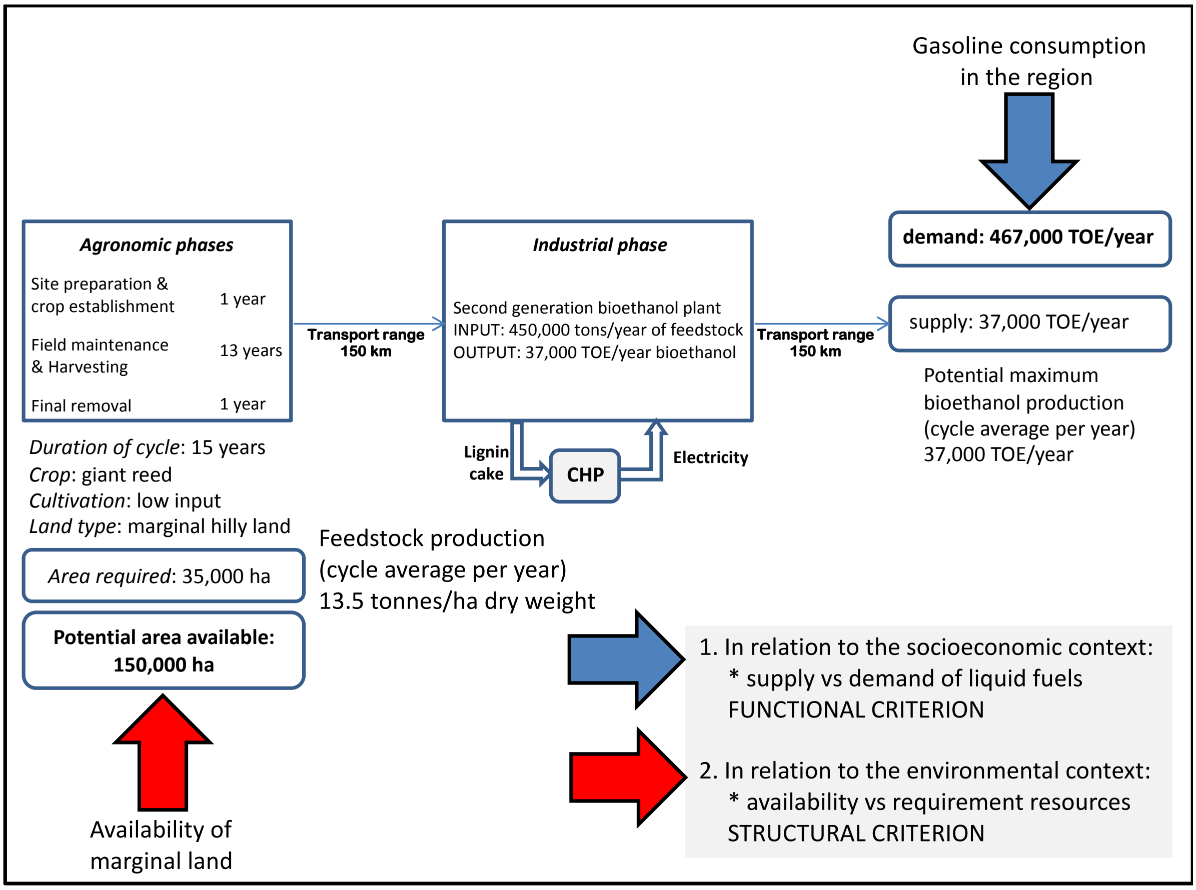

Fig 1: Characterization of the size of energy system in relation to its context: (1) functional criterion and (2) structural criterion.

2.2 Analytical framework for the characterization of the metabolic of the BioOH-PS

This study is for the authors a first attempt in obtaining a multi-criteria understanding of the territorial BioOH-PS by applying the MuSIASEM approach (Giampietro et al 2009; 2012; 2014). BioOH-PS can be defined by a dual criterion: functional and structural (Fig. 2). Cultivation area can be described as extensive system because surface variation can affect the energy gradient and consequently the operational capacity of the transformation plant (450k tons per year). Transformation plant can be considered as an intensive system whose flow of the final energy carrier will be influenced by the internal technical characteristics. It can become an extensive system by changing the operational capacity or the plant's number, according to energy carrier demand by territory (functional criterion) (Fig. 2).

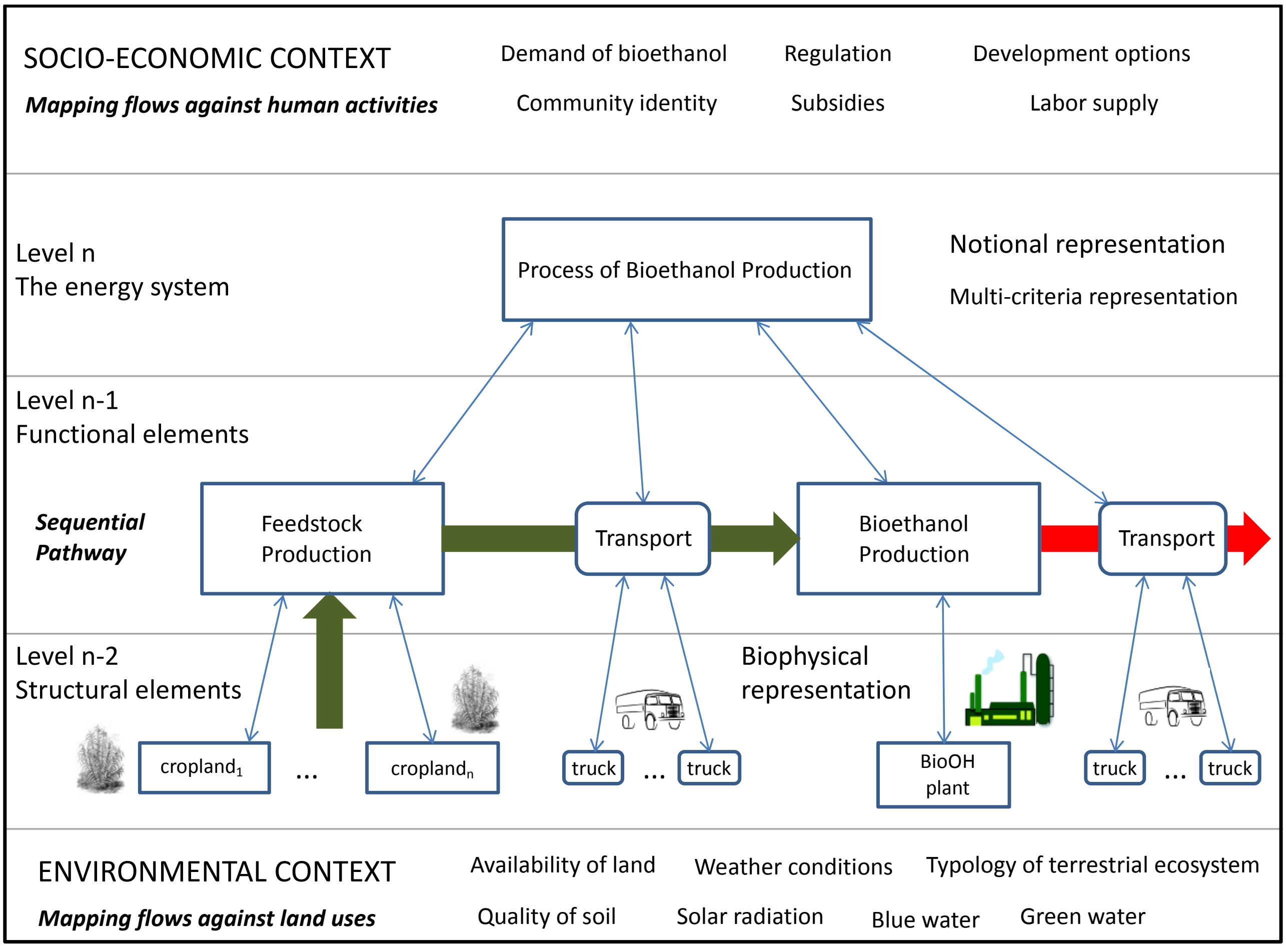

Fig. 2: Multi-purpose grammar describing the metabolic system that modulates the interaction between the metabolic needs of the society for energy use in transport.

Two features of the MuSIASEM approach are particularly useful for this study: (i) the representation of the metabolic system is semantically open – this fact makes it possible to describe the relations over functional and structural elements across different levels and scales as a set of relations that can be tailored on the specificity of the case study (the accounting is organized using grammar in the MuSIASEM jargon) (Figs. 2 and 3); (ii) the representation of the metabolic identity of the system in biophysical terms follows Georgescu-Roegen's flow-fund theoretical scheme (Fig. 3).

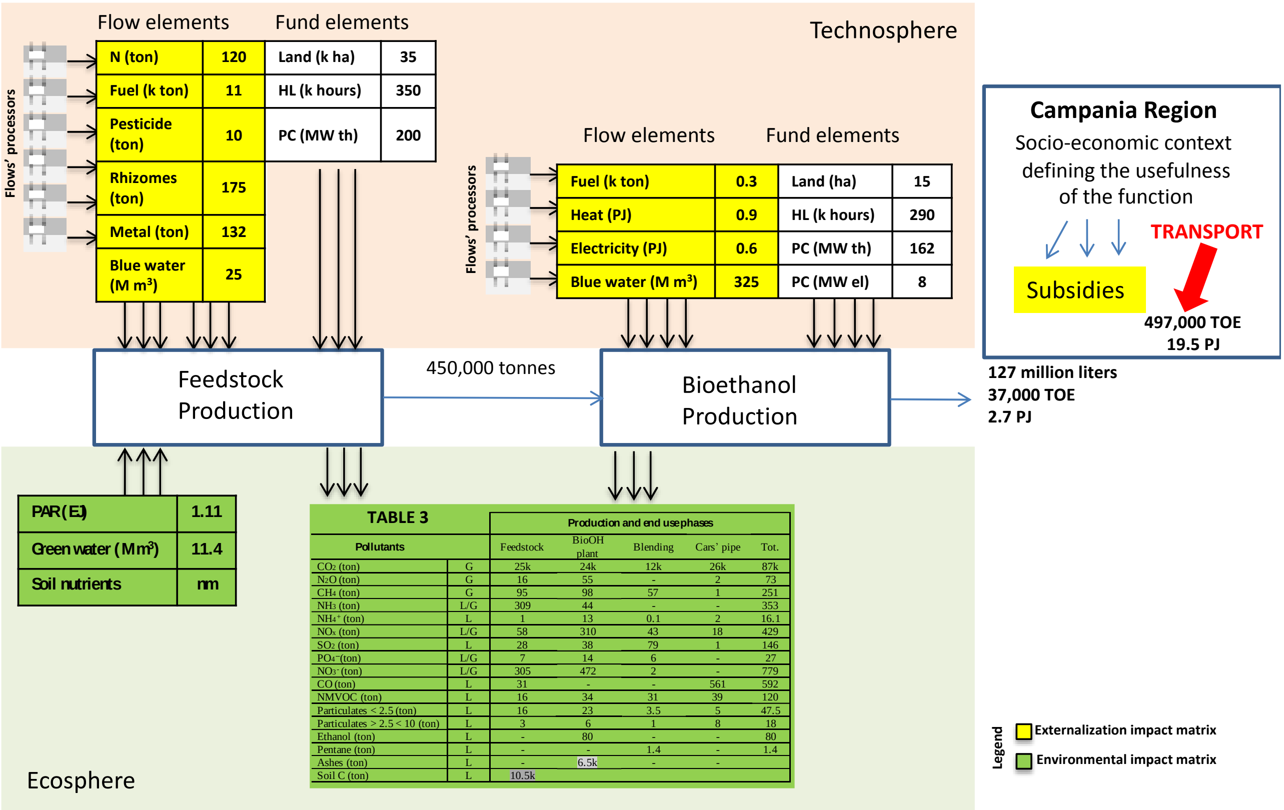

TABLE 3

Pollutants		Feedstock	BioOH plant	Blending	Cars' pipe	Tot.
		Production and end use phases				
CO_2 (ton)	G	25k	24k	12k	26k	87k
N_2O (ton)	G	16	55	-	2	73
CH_4 (ton)	G	95	98	57	1	251
NH_3 (ton)	L/G	309	44	-	-	353
NH_4^+ (ton)	L	1	13	0.1	2	16.1
NO_x (ton)	L/G	58	310	43	18	429
SO_2 (ton)	L	28	38	79	1	146
PO_4^- (ton)	L/G	7	14	6	-	27
NO_3^- (ton)	L/G	305	472	2	-	779
CO (ton)	L	31	-	-	561	592
NMVOC (ton)	L	16	34	31	39	120
Particulates < 2.5 (ton)	L	16	23	3.5	5	47.5
Particulates > 2.5 < 10 (ton)	L	3	6	1	8	18
Ethanol (ton)	L	-	80	-	-	80
Pentane (ton)	L	-	-	1.4	-	1.4
Ashes (ton)	L	-	6.5k	-	-	
Soil C (ton)	L	10.5k				

Fig. 3: The BioOH-PS grammar made analytically operational by means "processor" which assign an identity to the metabolic elements of the overall metabolic system. Relations between: (i) internal inputs and internal outputs, and (ii) external inputs and external outputs.

A grammar consists in a set of expected relations linking semantic categories (the different forms of matter and energy flows used in the process) and formal categories (their relative quantification) according to a given set of production rules characterized by specific technical coefficients and the relations in sequential and functional pathways (Giampietro et al., 2014). In this scheme (Fig. 3), flow elements are represented by energy and material flows disappearing and/or appearing (the different types of inputs and outputs) over the duration of the representation (time horizon of the analysis), while fund elements are represented by agents responsible for energy transformations (either production or consumption of flows) required to reproduce the identity of the metabolic pattern over the duration of the representation. Typical fund elements are technical capital (i.e. power capacity and infrastructures), human labor and land uses. This approach makes it possible to use simultaneously non-equivalent descriptive domains in an integrated representation (Figures 2 and 3). This feature is a must when dealing with sustainability issue in which relevant patterns can be only detected at different levels and scales (Giampietro and Mayumi, 2000). Thus, the BioOH-PS metabolic pattern is characterized by combining two complementary views (Fig. 3): (i) the external view (ecosphere) are the constraints outside human control on the transformation of Primary Energy Source (PES) into final Energy Carrier (EC); (ii) the internal view (technosphere) are the constraints under human control affecting the same transformation process (e.g., the technical coefficients of individual processes, availability of production factors). The BioOH-PS grammar, illustrated in Fig. 3, is made analytically operational by means of processors which assign an identity to the metabolic elements of the overall metabolic system. In fact, a processor coincides with the definition of a "metabolic identity" for each metabolic element. Processor establishes a relation between: (i) internal inputs and internal outputs, and (ii) external inputs and external outputs. Internal refers to two different typologies of elements that are consumed or produced (flows) and maintained (funds) by each metabolic system. Internal elements operate inside the technosphere and therefore they refer to inputs and outputs determined by processes that are under the human control with economic relevance. External refers to flows that are produced or received by the ecosphere and therefore outside the human control. They are essentially the ecosystem services fundamental for the production processes: (i) energy and matter flows from the ecosphere and (ii) matter flows towards the ecosphere.

In relation to this point the representation of our observed BioOH-PS (Figs. 2 and 3) is based on the identification of:

* *three functional compartments*: (i) feedstock production (very relevant for land uses); (ii) feedstock transformation (very relevant for technical capital use); and (iii) the actual supply for final use of energy carriers (relevant for assessing the usefulness of the system). This organization in a sequential pathway over expected functions to be expressed in the BioOH-PS frame the analysis of the structural elements required in each functional compartment, to guarantee its function;

* *three dimensions of analysis:* (i) technical/biophysical; (ii) economic; and (iii) environmental.

By adopting this approach, we have:

(i) analyzed the impredicative relation between external and internal characteristics. Changes in external constraints can affect the characteristics of internal processes (top-down causality) but at the same time changes in internal characteristics of the system that can redefine external constraints (bottom-up causality). This is made possible by the multi-purpose grammar as defined in Figure 2;

(ii) produced a more detailed analysis of the energetic performance of the system less simplistic of the Energy Return On the Energy Investment ratio (EROEI);

(iii) obtained a richer comparison between two different energy systems producing in different ways to different energy carriers: bioethanol and gasoline. That is we avoided a simplistic analysis of the two based on attributes of performance developed for the analysis of fossil energy fuel generation;

(iv) structured a robust and reliable evaluation framework able to evaluate the overall socio-ecological performance – i.e. considering both the technosphere and ecosphere point of view - tailored to a specific territorial and socio-economic context;

(v) generated a system of visualization of the overall performance of the energy systems easily understandable for end-users, where a top-down route (*ex post*) allows to generate an *ad hoc* participative evaluation in order to improve the bottom-up analysis (*ex ante*).

Beside the technical aspects related to the crunching of numbers, the Quantitative-Story Telling method addresses explicitly the need of checking the quality of the narratives underlying the generation of quantitative analysis. A narrative can be understood as a set of explanations used to justify the choice of a strategy (policy) for achieving the results. On the basis of this definition we can see a key relation between the pre-analytical perception of an issue (the choice of a narrative) and the analytical framework (the choice of data and models) used to generate the representation used to inform the final discussion. In this study we analysed the narrative of the proponents of a biorefinery perceiving this as a renewable energy system producing energy carriers (liquid fuels) in a sustainable way.

When applying the MuSIASEM approach we can identify a set of key factors relevant to analyze and understand the various aspects determining the sustainability of the energy system. In particular, what type of information is required to check: (i) the feasibility of the proposed system in relation to external constraints and environmental impact; (ii) the viability of the proposed system in relation its economic and technical viability; (iii) the level of openness (externality) of the whole BioOH-PS giving us relevant information about the system's dependence on external flows (energy, material, money); (iv) the desirability for farmers (an adequate profit), consumers (an adequate supply of renewable energy carrier), rural communities (an adequate solution to the problem of rural development).

2.3 Calculation and evaluation procedures of the relevant parameters characterizing BioOH-PS

2.3.1 Feedstock production phase: crop yields and running costs

Here we report some basic information about *Arundo donax* L. cultivation, details on yields' dynamic and additional feedstock data inputs are reported in Zucaro et al. (2016). The giant reed crop was conceived as a low input cropping system, without irrigation and only low nitrogen fertilization as urea (50 kg ha^{-1} yr^{-1}). The input flows included both the annual agricultural practices, N-fertilization for the field maintenance and harvest operations, as well as the phases for site preparation, seedbed preparation, crop establishment through rhizomes planting and final crop removal. The same agricultural practices were considered to evaluate the thermal power capacity of agricultural machines (MWth) and human labour (HL). Yearly mean biomass production of 13.5 t ha^{-1}, spread over 15 years of crop cultivation in hilly experimental fields, was considered. Taking into account this average annual productivity and feedstock's transformation capacity of the second-generation plant investigated (450,000 dry t yr^{-1}), a potential surface of 35k ha of marginal cultivable land is required (Fig. 1).

We evaluated the yearly running costs in producing giant reed on an area of one hectare of cropped field, taking into account that some practices were spread over 15 years. Our estimate accounted for a value of 640 € per hectare, referred to the following practices:

(i) seedbed preparation, 25 €;

(ii) crop establishment, 200 €;

(iii) field maintenance, 50 €;

(iv) harvesting, 350 €;
(v) explantation, 15 €.

Labor costs were not included in this assessment because the business reality of the territory is mainly made up of small individual businesses, as well as machinery purchase and/or rental, because considered as a machinery fleet already available. Our estimates are for low values of a range between 700 € and 1200 € reported by other studies (Lychnaras and Schneider, 2011; Corno et al., 2014; Fazio and Barbanti, 2014).

2.3.2 Bioethanol plant's running costs and profitability

A typical financial planning was applied in accordance with the standard approach proposed by Farbey et al. (1992) and Bromley et al. (1998), in order to evaluate the potential profitability of the biorefinery plant (internal point of view – economic coefficient). The analysis took into account costs (based on average values) of the period 2014-2016. Investment plan and employer plan were considered for a period of 10 years. Data set for the analysis of the transformation plant were obtained from Beta Renewables (http://www.betarenewables.com/it). The profitability assessment was achieved taking into account the main economic indexes: Return on Investment (ROI), Return on Sales (ROS), Capital Turnover and Return on Equity (ROE).

The financial planning was constructed considering the following plans: Investment Plan, Employer Plan and Sales Plan. More in detail, with the Investment Plan has been: (i) identified the capital asset planning initiative; (ii) quantified the capital need; and (iii) calculated same economic items, such as depreciation, finance charge and taxes (Table 1). As it relates to the Employer Plan, the potential people involved in the industrial plant starting from the start-up phase up to the full operation phase were taking into account (Table 2).

Table 1: Investment Plan. Specifically, it (i) identified the capital asset planning initiative; (ii) quantified the capital need; and (iii) calculated same economic items, such as deprecation, finance charge and taxes.

Investment Description	**Value (M€)**	**%**
INTANGIBLE ASSETS		
License	16.52	13.01%
Total Intangible Assets	***16.52***	**13.01%**
TANGIBLE ASSETS		
Land (15ha)	0.15	0.12%
Plant and machines	110.1	86.75%
Equipments	0.100	0.08%
Other goods (i.e. cars)	0.055	0.04%
Total Tangible Assets	***110.4***	***86.99%***
Total Investment	**126.92**	**100%**

As far as the Sales Plan was concerned, the expected revenue, during the operation of the advanced ethanol plant, were calculated. The forecast sales were calculated based on plant use (%) and the amount of expected produced ethanol (in liters) by the conversion facility; whilst revenues were calculated, multiplying the quantity of produced ethanol by the estimated ethanol-fuel price (per liter). Finally, in order to complete the financial planning, the variable costs were defined. The main component of these costs (approximately 30% of the production value) was represented by the purchase costs of lignocellulosic feedstock.

Table 2: Employer Plan. The potential people involved in the industrial plant starting from the start-up phase up to the full operation phase.

<table>
<tr><th></th><th>Employer requirement</th><th>Rules and contract class</th><th>Total Employer Costs (€/year)</th></tr>
<tr><td>Year 1</td><td>75</td><td rowspan="5">Management, business, and financial occupations (10%)
Class (A1)
Professional and related occupations (13%)
Class (A2, A3, B1,B2)
Sales and related occupations (3%)
Class (B1, B2, C1, C2, D1, D2, D3)
Office and administrative support occupations (11%)
Class (B2, C1, C2, D1, D2, D3, E2, E3)
Installation, maintenance, and repair occupations (9%)
Class (B2, C1, C2, D1, D2, D3, E1, E2, E3)
Production (44%)
Class (C1, C2, D1, D2, D3, E1, E2, E3)
Transportation and material moving occupations (10%)
Class (E3, F)</td><td>2,082,521.97</td></tr>
<tr><td>Year 2</td><td>100</td><td>2,776,695.96</td></tr>
<tr><td>Year 3</td><td>120</td><td>3,332,035.15</td></tr>
<tr><td>Year 4</td><td>150</td><td>4,165,043.93</td></tr>
<tr><td>Year 5</td><td>150</td><td>4,165,043.93</td></tr>
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2.3.3 Energy inputs

Fig. 4 reports the data on the scale of operational capacity of the BioOH-PS to transform lignocellulosic feedstock into biofuel and the resulting need of land to feed it. The two main energy fluxes entering in the metabolic system are represented by the direct solar energy and subsidiary fossil energy. Energy values are reported either in MJ that in TOE (tons of oil equivalent); the conversion factor considered was 1 TOE=41868 MJ (after IEA standard conversion factor).

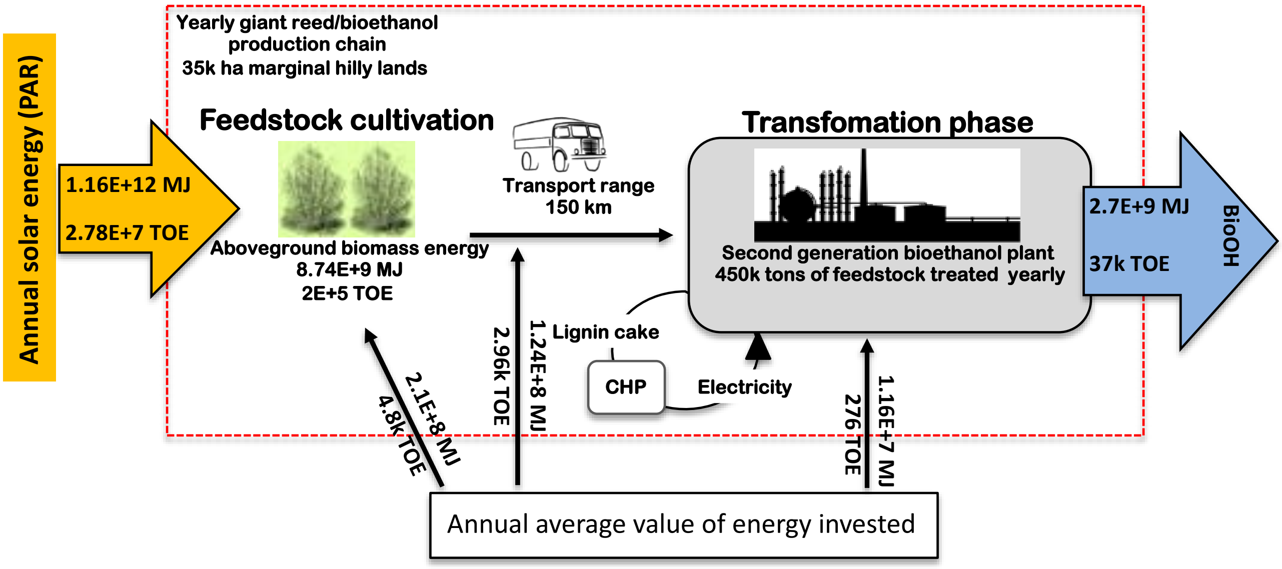

Fig. 4: Energy identity of the BioOH-PS on the scale of operational capacity.

Solar energy was expressed in PAR (Photosynthetic Active Radiation) that is 41% of the total solar energy. The values reported were referred to an annual value of incident solar energy over 35k hectare and considered the average solar energy value of 21 MJ m^2 day^{-1} at Campania region latitude.

The outside energy investment is related from field to plant gate and was obtained by more detailed study of Zucaro et al. (2016). It took into account the specific energy use for: (1) the crop phase of feedstock cultivation; (2) the transport of biomass from farm to bio-refinery; (3) the feedstock conversion through advanced second generation technology plant. Blending and distribution steps were also considered to calculate the energy ratio. The energy output was calculated considering the low heating value (LHV = 27MJ kg^{-1}) of ethanol (ENEA report, 2010; Directive 2009/28/EC) and converted in TOE (tons of oil equivalent). The energy ratios calculated (EO/EI) were 4.7 at plant gate.

2.3.4 Material flows and wastes outputs

The inventory primary data of the incoming matter flows were integrated with background data obtained from the EcoInvent database v. 2.2 in order to obtain the values from cradle to gate and from cradle to wheel of fossil fuel and blue water requirements.

Waste products of each single metabolic phase, have been evaluated through an attributional LCA (Zucaro et al. 2016). A “cradle-to-gate” and “cradle-to-wheel” attributional LCA was applied to the overall production chain. “Cradle-to-wheel” analysis was referred to E85 engine (85% EtOH and 15% gasoline). Standard procedures (ISO 14040-44: 2006) were applied by means of the SimaPro 8.2 software. The analysis encompassed the whole bio-ethanol (EtOH) supply chain: (i) from low-input lignocellulosic *Arundo donax* L feedstock cultivation on hilly marginal land, along the whole 15-year lifecycle; (ii) throughout biomass conversion to EtOH (99.7% in water) at the biorefinery plant, with restrained chemical inputs and energetic valorization of unconverted solids through combustion in an internal Combined Heating and Power (CHP) plant to produce on-site process heat and electricity; (iii) down to the final EtOH use in E85 flex-fuel vehicles.

Soil carbon storage was considered as an output parameter since giant reed crop has been selected in the project activities thanks to its ability to accumulate carbon in the soil through the high hypogeum productivity of the rhizomes. Light increase of soil organic carbon was detected, compared with previous wheat crop condition, and amounted to a mean value of 0.8 t ha^{-1}, corresponding to a storage pace of 0.26 t $ha^{-1}yr^{-1}$. This result is significantly lower compared with the best performance of forest systems, ranging between 1.5-4.5 t C $ha^{-1}yr^{-1}$(IPCC, 2013).

2.3.5 Energy demand of the local transport

The energy need of the regional transport sector, mainly focused on gasoline since fuel equivalent to bioethanol, was found out from Regional report (Lo stato della rete distribuzione carburanti della Campania, 2015). The value was expressed in TOE and amounted to 467k TOE per year.

3. Results and discussion

3.1 What the metabolic identity tells us at a first glance

The metabolic identity described in Fig. 3 allows us to obtain the first useful general picture of the metabolic system under observation. The definition of “renewable energy source”, sustained by the narrative, entails the concept of transforming with as high as possible level of efficiency the incoming flows from ecosphere, generating wastes’ flows compatible with the ecosphere functions (outside human control). Contrary to this statement, the BioOH-PS shows a metabolic identity unbalanced towards an important contribution of the technosphere, in its functional (flows) and structural (funds) component. The inflow contribution of the ecosphere (supply side of the environmental impact matrix represented by the green cells in Fig. 3) is simply limited to the solar source, the process of evapotranspiration and soil fertility (data not still available). On the other hand, the ecosphere must undergo the burden of the broad spectrum of metabolic waste (the environmental impact matrix in Fig. 3 and detailed numbers in Table 3), coming exclusively from the technosphere. Loss of macro and micro nutrients, contained in the ashes produced as by-product by the co-generation plant (CHP), represents a loss of soil fertility properties.

Therefore, the exploitation of the primary source considered free, unlimited and renewable, must put on a productive fabric heavily dependent on the technosphere. The yellow cells of Fig. 3 (externalization matrix) indicate the flows from technosphere necessary for the functioning of the BioOH-PS, thus highlighting the low autonomy of the system and the heavy dependence on other processors necessary to generate the incoming flows. The emissions reported in Table 3 also include the contribution of these flows. This is well evident for the feedstock production phase with inevitable repercussions on the operating costs of the agronomic phase (Fig. 6). The whole production system also appears dependent on its operation by a massive component of funds, that also in this case affects the operating costs (Fig. 6). This represents a critical issue, since the reduced costs of energy is one of the most important objectives for the economic development.

Table 3: Yearly emissions of pollutants emitted by the territorial BioOH-PS and final use of the energy carrier. The data are disaggregated to identify the impacts of each individual phase. Emissions are related with potential local (L) and global (G) effects.

		Production and end use phases				
Pollutants		Feedstock	BioOH plant	Blending	Cars' pipe	Tot.
CO_2 (ton)	G	25k	24k	12k	26k	87k
N_2O (ton)	G	16	55	-	2	73
CH_4 (ton)	G	95	98	57	1	251
NH_3 (ton)	L/G	309	44	-	-	353
NH_4^+ (ton)	L	1	13	0.1	2	16.1
NO_x (ton)	L/G	58	310	43	18	429
SO_2 (ton)	L	28	38	79	1	146
PO_4^{---}(ton)	L/G	7	14	6	-	27
NO_3^- (ton)	L/G	305	472	2	-	779
CO (ton)	L	31	-	-	561	592
NMVOC (ton)	L	16	34	31	39	120
Particulates < 2.5 (ton)	L	16	23	3.5	5	47.5
Particulates > 2.5 < 10 (ton)	L	3	6	1	8	18
Ethanol (ton)	L	-	80	-	-	80
Pentane (ton)	L	-	-	1.4	-	1.4
Ashes (ton)	L	-	6.5k	-	-	
Soil C (ton)	L	10.5k				

For this output the landfill disposal scenario must be considered (light grey)
This output value must be confirmed at the end of the crop cycle after the biomass eradication (dark grey)

3.2 A more detailed focus on the territorial BioOH-PS as energy converter: beyond the EROEI

The energy performance is a pivotal feature of this study, since the analyzed system has been conceived to perform an energy transformation process to produce an appropriate energy carrier and it is part of the discussion of the viability performance. One of the R&D goals of the ENERBIOCHEM project was to improve the energy efficiency of the overall production chain (from field to plant gate) in order to improve the output/input energy ratio (Energy Return On the Energy Investment ratio - EROEI). The energy ratio performance has always been reported in the literature as the weak point of any biofuel production system, mainly in relation to gasoline, that performs higher EROEI (Gomiero, 2015). Hall et al. (2014) discussed the critical issues in the EROEI evaluation as an effective indicator of providing comparative assessments among energy production systems, mostly due to the choice of direct and indirect costs associated with energy production/extraction (boundaries choice). As pointed out by Diaz-Maurin and Giampietro (2013), analyses based only on EROEI are limited to a mono-dimensional indicator and cope with one single scale, so are unsuitable to tackle the issues related to the quality of an alternative energy carrier like biofuel. In this discussion we intend to address the reader about some of the intrinsic weaknesses of the EROEI from a theoretical point of view along with the practical and try to summarize them without a long digression. It cannot overcome the unavoidable ambiguity of the definition of the label "energy", mainly in relation to socio-economic context (supply *vs* demand). Quantities of energy belonging to the category of PES, in our case solar photonic energy, are not the same as quantities of energy belonging to the category of EC, in our case thermal properties of the final bioethanol. Classic approach of assessing EROEI is a simplification cannot provide several fundamental information. We have based our discussion on the reflections of Giampietro and Sorman (2012), which claim the need to evaluate the processes of energy transformation, taking into account three basic semantic categories: primary energy sources, energy carriers and energy end-uses.

The EROEI estimated for bio-ethanol derived from giant reed via the present study achieves a value as high as 4.7 at the plant gate. This value allows us to get only two information: (i) a significant improvement of the energy ratio compared with first generation bioethanol, above all compared to bioethanol from corn (Gomiero, 2015); (ii) a significant lower value than the current energy ratio of gasoline (Gomiero, 2015). On the contrary, it does not provide relevant information in relation to socio-ecological criterion: (i) how much primary source is converted; (ii) how much land is required to feed the transformation plant; (iii) what is the technical effort (power capacity); (iv) how much human labour is required to obtain the energy carrier; (v) how much limiting is the feedstock production phase, particularly in reference to the abundance (power density) and constancy (intermittency) of flow; (vi) what are the characteristics of consumption side, not only in relation to energy needs but also to consumers' acceptance. Such type of information can be deduced only by means of a robust story-telling able to connect the characteristics of the semantic categories of the overall metabolic identity with flows and the contribution of each fund and the flow/fund ratio. Moreover, the positive value of the energy ratio actually blinds the thermodynamic cost of the overall process. Outputs cannot be larger than inputs in energy transformations, therefore the fact that the output/input of bioethanol is positive depends on the consumption of a larger quantity of solar primary energy source and the use of a large area of land with related biomass produced, in generating the proper energy gradient. Solar energy exploitation requires investing production factors such as: (i) available energy carriers; (ii) power capacity; and (iii) labor. These production factors must be used as inputs in the process generating a net supply of energy carriers. This simple statement clearly indicates that if we want to characterize the performance of energy systems we have to use more than a single quantitative variable (Diaz-Maurin and Giampietro, 2013).

In more detail, the yearly photosynthetically useful energy expressed as PAR (Photosynthetic Active Radiation), on the total soil surface necessary to feed the bioethanol plant, exceeds by nearly sixty times the needs of the regional gasoline energy for transport (Fig. 5). The overall energy flux from sun to bioethanol was characterized by some bottlenecks (Fig. 5), indicating that processes under human control are not so efficient in transforming the abundant primary source. The overall net performance from solar available energy (PAR) to bioethanol was 0.011%, including in the account the energy investment from technosphere to power the thermal and electrical capacity for crop field and transformation phase, as well as the up-stream processes (Fig. 3). The limited amount of solar energy useful for the photosynthetic process, is totally outside the human control since it depends by the leaves' pigments apparatus. The yearly solar energy, over the surface of 35k ha cultivated with giant reed, amounts to 2.7EJ, only 1.11EJ (Photosynthetic Active Radiation) is available for the photosynthetic apparatus, the remaining part plays an indirect effect on the biomass productivity (evapotranspiration, thermal properties affecting root and soil biological activities). The most prominent bottleneck, partially under the human control, is represented by the crop photosynthetic solar energy transformation into the aboveground net primary productivity (NPP). An efficiency of 0.75% was observed, which further reduction to 0.73% accounting the auxiliary energy (Fig. 5).

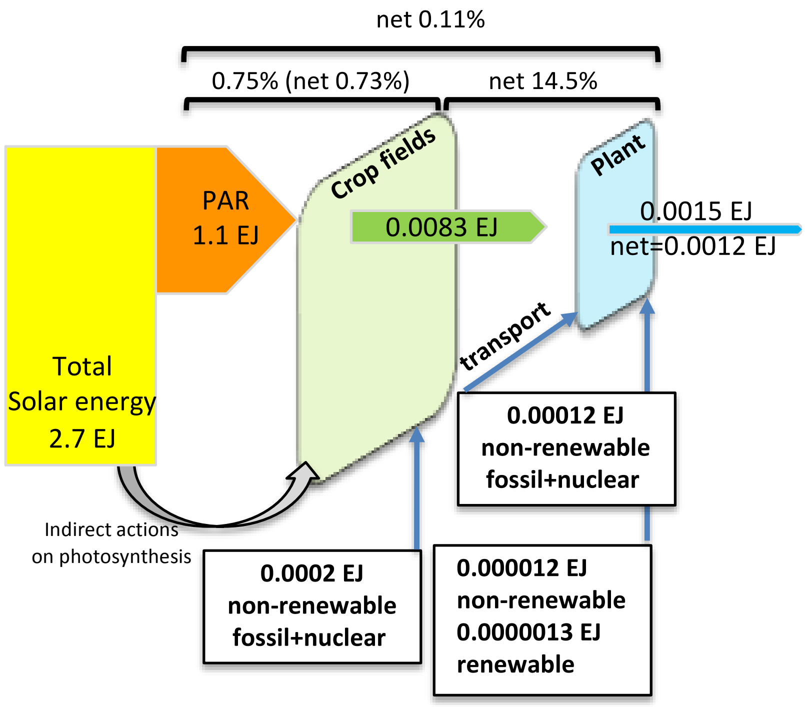

Fig. 5: Converter 's efficiency from Primary Energy Source (PES) to Energy Carrier (EC).

A substantial bottleneck was detected for the transformation phase of feedstock into bioethanol as well. The gross efficiency was 18%, with a reduction to 14.5%, accounting the energy investment in the two phases of field crop and feedstock transformation (Fig. 5). A large energy investment was mainly charged to the feedstock's transport.
The whole BioOH-PS showed to be highly dependent on thermal work, for the local transformation phases (Fig 3) and the upstream process steps. As such it was therefore heavily dependent on non-renewable energy, for over 90% of fossil origin. A future

scenario of a totally renewable energy supply chain towards the BioOH-PS, would mean that part of the energy produced by the system will be used to fuel the thermal capacity of the same production system.

The flow/fund ratios can further define the metabolic identity of the BioOH-PS and its performance. The energy flow on the incoming PAR expressed over the land surface (W/m^2), also known as power density, was equal to 100 W/m^2. While the power density of energy of the bioethanol at plant gate reduced drastically to 0.11 W/m^2, a value significantly much lower than the fossil sources that measure values between 1000 and 10,000 W/m^2 (Smil, 2003; Smil, 2010). Since the current metabolic requirement of private transport has been consolidated on the basis of the power density offered by the fossil fuels, it will be difficult for bioethanol to guarantee the same efficiency of gasoline in the near future.

The power capacity (measured in watts) indicates what asset of converters are used by the overall energy BioOH-PS to generate the power output. Figure 3 reports the power capacity invested across the whole steps of the BioOH-PS, which amounts to 370 MW, almost all of thermal nature (362 MW) mainly invested for thermal machines in the phases of crop management and feedstock transport. This bioethanol production system requires yearly a power capacity of 308 kW in producing 1 TJ of final energy carrier.

Human labor invested per unit of energy delivered as the energy carrier is an useful information in evaluating the performance of the energy transformation system. Our evaluation detected a supply of 1.9 GJ of bioethanol per hour of labor. This value certainly indicates a significant improvement compared to Brazilian bioethanol from sugarcane, as estimated by Giampietro and Mayumi (2009) showing a production of ethanol of about 0.5 GJ of liquid fuel per hour of labor. Instead, it's still lower of almost 4 times of a similar analysis of Aragão and Giampietro (2016) for the Brazilian oil and gas sector that showed 7GJ per hour of labor. These data, even if referring to countries with different socio-economic conditions, allow us to highlight anyway the difference in labor productivity between the production of ethanol and of fuels from fossil energy. This difference points out the lower economic convenience of the second generation bioethanol compared to the production of gasoline from oil, this topic will be discussed in more detail the next section.

3.3 Structural elements affecting the efficiency of the energy converter.

The required functions to BioOH-PS of energy converter are strongly affected by the impredicative relations among structural and functional levels, with significant impacts on the viability performance. Some critical points can be identified, especially in the crop production phase. A first significant issue of discussion is given by the capacity of the marginal agricultural territory to supply annually the BioOH-Plant with the proper amount of feedstock. The estimated cultivable land of 35k ha cannot be considered as a fixed surface able to feed with the constant amount of 450k tons the transformation plant. Several factors can act on the intermittency of the feedstock stream towards the transformation plant and can be listed as follows.

(i) Temporal and spatial variability of biomass production. The estimated yearly mean production value of 13.5 t ha^{-1}, spread over 15 years of crop cultivation in hilly

experimental fields, is actually a value referred to the experimental trials performed in few hectares over 15 years that showed a bell-shaped pattern. Average yields at the end of the crop phase decreased to values similar to the 1^{st}-2^{nd} year of cultivation. Productive temporal variability is not only referred to the 15 years cycle crops but also to the unpredictable seasonal variability due to several reasons like pests and climate action. The spatial and temporal variability of biomass production inevitably entails the need for an agricultural management planning on a territorial scale to avoid intermittence and ensure a constant synchronized flow of raw material to the processing plant. This type of planning has to be made operational through *collective contracts*. It is essential by the fact that the wide agricultural territory necessary to feed the transformation plant is made by an entrepreneurial reality of the territory considered in this study made of small companies that extend over areas of a few tens of hectares. In addition to the difficulties inherent in this type of contracting for a period of 15 years (cycle crop period), at the current state of facts of the territory of the Region, various critical issues could make this type of contract impractical in the short term: (i) the lack of generational turnover in the agricultural sector; (ii) the current trend of young farmers towards niche and quality products with further economic implications in other sectors such as tourism (a current trend broadly covered by local press).

3.4 Economic identity of the BioOH-PS

Fundamental condition for the survival of the BioOH-PS is the ability to generate a desirable profit between the two main economic actors, involved in the production chain, farmers and energy entrepreneur, together with the possibility of offering to consumers a final product with a competitive price, compared with gasoline. Figure 6 summarizes the economic identity of the territorial biorefinery, highlighting different constraints affecting its economic success inside the territory. They can be identified and synthesized:

(i) high running costs of the agronomic phase that make the feedstock price a limiting factor for the running costs of the production plant;

(ii) the consequent need for intervention by public incentives to ensure the desirability of the farmers;

(iii) the uncompetitive price of bio ethanol since the high investments and running costs;

(iv) consequences on consumer acceptance, together with other factors.

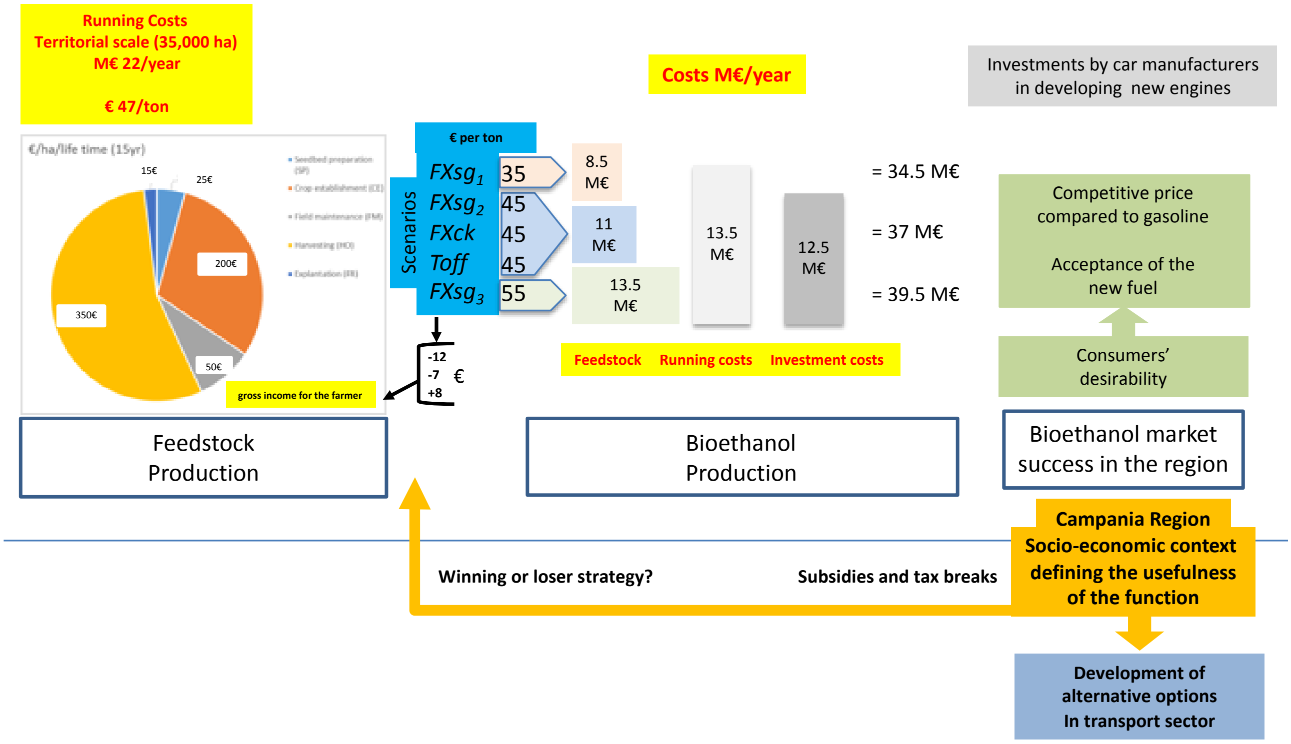

Fig. 6: Economic identity of the territorial biorefinery.

In more detail, Table 4 proposes some scenarios, taking into account three economic point of views: farmers, energy entrepreneur and consumers. In any case the energy entrepreneur's point of view is the decisive one, because is the main driver of the narrative. We considered five scenarios, in which feedstock's selling price and bioethanol purchase price are variables affecting the plant's profitability, whose investments and employer plans reported in tables 1 and 2 are considered constant. The reported scenarios can be considered as trade-off among the actors involved in the economic chain. Even if a fourth actor, namely the public sector, appears to be necessary in some scenarios through incentives, thus affecting the institutional viability of the whole BioOH-PS and a low performance in the externalization indicator since the system will depend by an external monetary flow (Fig. 6). This is because the scenarios we evaluated took into account the need for provide an active income to the energy entrepreneur within ten years from the investment. For example, we didn't take into consideration scenario purchasing the feedstock at 55 € per ton (favourable price for farmers without public incentive) and the sale of the bioethanol at 0.45 €/l (competitive price with gasoline) because absolutely disadvantageous for the entrepreneur since a payback period much larger than 10 years. We also proposed scenarios where the selling price of bioethanol is quite competitive with gasoline. With the sole exception of the price of 55€ per ton of feedstock, the other two purchase scenarios (35 € and 45 € per ton) are well below the crop management costs (640 € per hectare) and therefore require public incentives, in order to guarantee the interest of farmers to be part of the supply chain.

Table 4: Profit scenarios based on the point of views of the three actors involved in the overall chain: farmers, energy entrepreneur and consumers.

	Farmers	**BioOH entrepreneur**				**Buyer BioOH**
Scenarios	Feedstock selling price (€ per ton)	ROI	ROS	ROE	Active from (Year)	Purchase price (€ per liter)
FXsg₁	35	4%	11%	4.4%	6th	0.50
FXsg₂	45	10%	28%	13%	9th	0.50
FXck	45	7%	20%	47.9%	9th	0.45
Toff	45	3%	8%	1.2%	6th	0.52
FXsg₃	55	7%	20%	22.8%	9th	0.50

Scenarios $FXsg_1$, $FXsg_2$ and $FXsg_3$ (Table 4) took into account a selling price of bioethanol, set at 0.50 €, such as to guarantee at the same time an acceptable payback period and a final price to gas station comparable with gasoline (considering that purchase price by buyers was 0.45€ on average during 2016), the year the study was carried out) and variable feedstock's costs, 35 € per ton (advantageous for entrepreneur with public incentive), 45 € per ton (trade off with public incentive), 55 € per ton (advantageous for farmers without public incentive).

Scenario $FXsg_1$ highlighted an operating profitability positive since the sixth year, even if in a restrained way. It was strictly dependent by the total income and measured by Return on Investment (ROI). The Capital Turnover (income divided investment), was about 0.4, while the profitability of sales (ROS) was 11% and steadily grown up to 35% in the ninth year until 47% in the tenth year. At the same time, the Return on Equity (ROE) was positive from the sixth year, with significant increases from year to year that led to a positive 13% in the last year of investigation (tenth year).

Scenario $FXsg_2$ showed a growing trend of ROI, which was positive from the sixth year and gradually increased, thanks to the ROS performance that ranking in the last year values of about 40%. ROE was positive since the ninth year, when the biorefinery plant generated its first net profit.

Scenario $FXsg_3$ basically highlighted similar results to the previous one.

Scenario *FXck*, was chosen was introduced because it fixes the cost of the feedstock at a trade-off value for entrepreneur and with a lower public incentive; moreover, it proposed a competitive selling price of bioethanol with the gasoline (0.45 €/l). This solution showed a positive operating profit only from the ninth year, however operating income and net income were well below the threshold that can ensure sustainability of investment.

Scenario *Toff* was proposed to guarantee the proper trade-off between purchase price of feedstock sustained by the entrepreneur and medium public incentive, trying to guarantee a return on investment with a high selling price of bioethanol (0.52 €/l). This scenario showed a return on investment starting from the sixth year, pointing out an operational profitability but generating an insufficient market success since poor competitive with gasoline. In the latter case the ROI is growing up to a 13% thanks to a good return on sales, therefore this scenario provided the best results in terms of overall profitability.

Although it should be considered that the price of 0.52€/l could be overpriced for the Italian market.

These results have highlighted substantial weakness in economic viability based on the canonical principles of economic profitability. They evidenced that BioOH plant generates late operational profitability, beyond the time considered admissible by an enterprise (Phillips, 1996). The low profitability can represent a notable fact explaining the current Italian low development of bioethanol production, about 0.25% of ethanol market (Gnansounou, 2010). An *et al.* (2011) reported that the major obstacles to make operative a second generation bioethanol on a commercial scale is the high investment and operating costs.

The overall profitability was mainly affected by the feedstock cost (farmers' desirability) and final cost of fuel (consumers' desirability), in addition to operating costs. Even the intervention of public incentives, to guarantee the interest of farmers to be part of the production chain, cannot guarantee an appropriate economic success for the entrepreneur. Otherwise we could think of incentives that represent an externality as well as a failure for the autonomous capacity of the system (Fig. 6).

One of the aspects characterizing the narrative of a territorial bioethanol production system is that of guaranteeing new job opportunities an economic recovery in marginal areas. This aspect shows several weaknesses. First of all, a territorial bioethanol production system can generate new jobs only in the processing phase (few hundred units for the conversion plant), but it will not do so in the agricultural sector since there is only a conversion of the farmers, from food to energy. The low profitability could not be a valid solution to contrast the local trend of rural depopulation. Probably young farmers will be more focused on the opportunity to receive public incentives to enhance products of excellence typical of the area, cradle of the Mediterranean diet.

A considerable aspect is represented by the commitment of human labour as well. As pointed out by Gomiero (2015), developed countries are characterized by allocating a small fraction of their working time to the energy production sector. This allows a reduction in the cost of energy, one of the most important objectives in order to achieve economic development, and to invest human working time in other profitable activities.

3.5 The environmental burden of the BioOH-PS: beyond the single environmental topic of decarbonization.

Environmental issues are very complex and uncertain because for a correct interpretation of the impacts of an anthropic metabolic system it is not enough to quantify the catabolites but it is essential to know their impacts on a specific socio-ecological fabric. It is frequently observed a dramatic simplification of the facts, as in the case of one of the key topics of the narrative in support of bioethanol that assign the renewable label for its ability to decarbonize the energy sector. Studies that evaluate this environmental performance are based on the Life Cycle Assessment (LCA) approach, showing a significant net reduction in green-house gases emissions of second generation biofuels compared with the fossil counterpart (Whitaker et al., 2010; Forte et al., 2018). This result is obvious and expected since the LCA analytical framework detect the closed loop of the carbon dioxide. Our previous study (Forte et al., 2018) applied an attributional cradle-to-wheel assessment of carbon footprint investigating the same BioOH-PS under higher N fertilization rates. Carbon footprint benefit of E85 car compared with E3 gasoline car showed a reduced green-house gases emission by about 60% to 87%, the best performance was measured when the soil carbon storage capacity was considered in the calculation. The soil carbon storage, reported in Table 3, would save 25 g CO_2 eq per MJ. As already discussed in Forte et al. (2018), this value is still uncertain since in the current state of the agronomic trials we don't still have the soil response to the final eradication phase, characterized by a deep soil processing affecting the oxidative process of soil organic matter. Moreover, this issue is still controversial due to reliable extrapolation on a territorial scale and on a wider time scale. Entering even more in detail of the analysis, the bioethanol benefit was entailed only at the car use phase, due to the higher number of carbon atoms in gasoline compared with bioethanol, whilst the bioethanol supply chain (from field to biorefinery gate) showed a carbon footprint comparable to gasoline supply chain (from extraction to refinery) (Forte et al., 2018). On the other hand, gasoline cars highlighted a greater potential impact than bioethanol for other categories with local action: Terrestrial Acidification, Marine Eutrophication, Freshwater Eutrophication, Particulate Matter Formation and Water Depletion (Zucaro et al, 2016).

This should make us reflect on the fact that renewable label based on the single topic of decarbonization, as dictated by the legislator and then perceived as "the problem" in the imagination of the community, it can determine a simplistic interpretation and characterization of "the problem" and mask other important topics. A note to be added in this discussion is related to the difference in performance of the carbon footprint that is only evident in the tailpipe emission phase, suggesting the need to intervene mainly on transport strategies.

Moreover, LCA generates a high resolution evaluation of catabolic outputs at the scale of the analyzed production system, in a few words it says us how the system metabolize the input flows. Such approach can furnish reliable information to check the production chain's hotspots in order to improve the environmental performance in the detailed scale of each production phase. In the case of the presented study LCA approach gave us information about the environmental domain (pollutants emissions) for each considered level and at the metabolic scale of transformation and final use phase. These analytical outputs alone are not sufficient to assign the sustainability label at the BioOH-PS, as is widely done in the literature. LCA leaves much information unresolved, especially on larger scales that are able to provide more useful information for regional decision making. This aspect of scale extension is taken into account in the commercial LCA software by means of the Midpoint hierarchical level to relate on larger scale the impacts. For example, ReCiPe Midpoint method is related to European condition (Europe ReCiPe H). For this reason, the mid-point results produce only potential impact values since they are not able to produce reliable and accurate information about the capacities of local ecosystems to respond to the pressures exerted by the metabolic system.

In this discussion, we limit to offering a starting point for reflection on the potentiality of the MuSIASEM approach in connecting the domains of viability, feasibility and desirability, on a specific territorial scale, by applying the DPSIR concept, to achieve different objectives: (i) transforming the values of potential environmental impact into actual impact on the territory; (ii) monitoring the effects of the driver on the flows and on the funds of the metabolic system; (iii) interaction and implementation of normative aspects for impact assessment; (iv) relate the pressures exerted by the BioOH-PS driver to food production and ecosystem services.

3.6 The simplistic and harmful concept of marginal land in the biorefinery narrative

The canonical and widespread definition of marginal lands is that which gives these lands a poor agricultural value (Baumol and Blinder, 2011). This definition applied in the context of a developed socio-economic system implicitly contains the concept of economic profit. Natural causes (poor soil quality and water supply) and anthropic causes (pollution and over-exploitation) are responsible for their marginalization. This concept can therefore be considered rhetorical since different points of view can assign to the marginal lands a different meaning and roles. Only in a logic of the societal metabolism the rhetorical perception of marginal lands fails. Through a holistic perception, based on the overall societal metabolism (nexus among energy, food and water) we can have the proper perception of the marginal lands (Giampietro et al., 2014). If a significant portion of land dedicated to food production could simultaneously produce second-generation biofuels, some extent of agricultural expansion will be necessary if we are to meet our demands for both food and fuel. In fact, if until today a society has used the lands for nutritional metabolism, a partial use of these for energy metabolism implies the need to find new lands to ensure the unchanged societal nutritional metabolism. Since human populations live in a finite world, this will inevitably imply the marginalization due to over-exploitation of other agricultural lands for nutritional purpose, both in the region and outside the region. As already highlighted by Young (1999), this generates the concept of "surplus land" as a sort of reassurance that there will be plenty of land to meet future global demands. This perception thus highlights the weakness of the rationale of second-generation biofuels that do not conflict with food production. Therefore, this simplistic perception of marginal lands as a promising space resource for energy purposes can be dangerous in light of future scenarios for food security. Nalepa e Bauer (2012) have well described the problematic concept. First, it violates the principle of Ricardian rent, one of the most established in economic theory. This principle dictates that the best land will be used first since its cultivation relative to poorer quality land results in lower production costs and higher yields. Policy and socioeconomic factors, of course, may alter land use decisions and land productivity, but Ricardian rent assumes that land quality is an inherent and quasi-permanent characteristic that will render certain areas better suited for agriculture than others. Put simply, if there were the amount of quality surplus land that some estimates claim, farming on poorer quality soils would not exist to the extent that it does.

The concept of marginal land has to be applied on a local scale, taking into account specific socioeconomic characteristics. In the case of this study, marginal lands derived from the agricultural over-exploitation of hilly lands of the region. The narrative of the ENERBIOCHEM project claimed the possibility of restoring economic and agronomic value of these regional marginal lands through the cultivation of giant reed. The results discussed in the previous session showed that the economic valorization is characterized by several criticalities that do not allow to satisfy the narrative. In a logic of territorial interpretation on the regional scale, the biorefinery in any case exerts an environmental pressure that can affect other territorial activities with greater economic and socio-cultural added value. Based on our economic evaluations, the territorial biorefinery system must be supported with public incentives, it can probably not be considered a valid solution to raise the agricultural sector of the region.

4. Conclusion

BioOH-PS is an inefficient solar energy converter.

Our evidence, discussed in the specific session, shows that the system is not an effective primary energy converter, contrary to the narrative that identifies in the BioOH-PS an effective converter of solar primary energy to satisfy societal energy demand. Only 0.11% of incoming solar energy is converted into the final energy carrier, several bottle-necks have been detected, mainly charged to the cultivation phase. The system depends heavily on the technosphere by means of investments in auxiliary energy and materials (flow elements) to ensure maintenance and operation of the funds elements. These facts highlight what Cottrell (1955) already discussed several decades ago. He explained that in converting energy, from a primary energy source into an useful energy carrier, is the nature of the converter that determines what should be considered as potential energy input.

BioOH-PS does not fully meet the expectations of a renewable energy carrier producer.

The adjective renewable is a label, assigned to bioethanol, that if it is not faced in its complexity can generate false enthusiasms. It is not enough to assign this label to the energy carrier only because it derives from the continuous flow of solar energy, free, unlimited and abundant, from whose combustion a closed carbon loop can be generated. In order to assign such label, functional and structural characteristics of the energy conversion system have to be considered. The concept of renewability must also include the capacity for autonomy of the overall energy transformation system. The technical structure of the whole BioOH-PS, expressed by the funds elements and the flows necessary for its operation, appeared highly dependent by external systems; particularly on thermal work, for the local transformation phases and the upstream process steps. In a future scenario of total independence from the fossil resource and then towards a totally renewable energy supply chain, would mean that part of the energy produced by the system will be used to fuel the thermal capacity of the same production system.

BioOH-PS is not a winning strategy for decarbonization strategies.

The concept of decarbonization assigned to bioethanol, is related to the fossil counterpart. Our analyzes, already presented in previous publications, have shown a benefit of bioethanol in the decarbonization process, with reference to gasoline, only in the complete supply chain from the primary energy source up to the final use. Instead, limiting the analysis to the plant gate, data showed no differences. This result indicates that the decarbonization strategies are obviously associated with the high energy request of the transport sector. Therefore, the solutions should not be sought on alternative fuels to gasoline which, as in this case, would show the many critical issues that emerged from this study. Solutions have to be identified in other logistics strategies to be applied to transport sector in obtaining significant results towards decarbonization policies. The results that we present should be a starting point for decision makers to evaluate different solutions, for example strategies aimed at optimizing the logistic network of transports able to obtain an advantageous relationship between energy used for transported persons.

BioOH-PS pays the price of the low power density value: land use vs fossil depletion.
The effectiveness of an energy system is not only assessed through the study of the energy converter, but must also take into account the final energy demand of the society, since the latter is the main driver affecting the metabolic identity of the converter. The current energy demand of the transport sector is commensurate with the high energy gradient (power density) offered by fossil fuels. Bioethanol, to guarantee the same energy gradient, must necessarily structure the converter exploiting the extension of arable lands, since that in the near or distant future we cannot expect a significant improvement in biomass productivity, particularly in the area of the Mediterranean basin due to the effects of the expected climate change. From this point of view, bioethanol is still far from fulfilling a promising competition with gasoline. The only effective alternative is to reduce the energy demand of transport. In any case, the worldwide current development strategies of car manufacturers do not seem oriented towards the development of engines for bioethanol but rather towards electric cars.

BioOH-PS is not exempt from environmental impacts.
The environmental impact cannot be simplified only on the effects of a metabolic system on climate change. Our analytical evidence shows that the solar energy transformation system is strongly dependent by the technosphere, loading a significant environmental burden on the ecosphere, both at plant gate and tailpipe emission. Most of the impacts take place on a local scale, suggesting the need at developing a more reliable approach in order to generate a more detailed site-specific socio-ecological assessment for local participative processes for decision making. The participative process should be able to involve the territorial social fabric to evaluate the pros and cons of the local biorefinery and therefore a desirability of a broader social context. As in this case study, the alternative bio-energy production system generates environmental impacts with potential local effects on health, eutrophication and therefore on other local production sectors such as agriculture and tourism.

BioOH-PS doesn't appear as promising strategy to drive the local rural economy revaluating marginal lands
The inability of the energy conversion system to use the free services of the ecosphere with maximum efficiency, inevitably affects the high operating costs for the intervention of the technosphere to support the process. The criticality of costs both in the agricultural phase and in the transformation phase, with effects on the final cost of the product and ultimately on the system's ability to survive on an economic logic. The intervention of public incentives, in addition to representing an externality, could represent a non-

winning strategy in long-term perspective. Moreover, the rural characteristics of the Campania Region (high tourist and landscape value, cradle of several high-quality products) may not meet the desire of young entrepreneurs in the sector. Therefore, political advances are necessary, alternatives to the energy sector, also in the light of what was discussed in the previous session on the risk of assigning a simplistic definition to marginal lands.

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