CERESiS: ContaminatEd land Remediation through Energy crops for Soil improvement to liquid biofuel Strategies

D1.5: Definition of sustainability Key Performance Indicators (S-KPIs) for integrated solution pathways

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Contents

ABBREVIATIONS

ANEP	:	Annual Net Energy Production
BCR	:	Benefits to Costs Ratio
BOD	:	Biochemical oxygen demand
BTL	:	Biomass to Liquid
COD	:	Chemical oxygen demand
DALY	:	Disability Affected Life Years
DCF	:	Discounted Cash Flow
DPB	:	Discounted Payback
DSS	:	Decision Support System
EE	:	Environmental Economics
EESI	:	Environment and Energy Study Institute
EIA	:	Environmental impact assessment
EPBT	:	Energy PayBack Time
ERO(E)I	:	Energy Returned On (energy) invested
GBEP	:	Global Bioenergy Partnership
GDP	:	Gross Domestic Product
GHG	:	Greenhouse Gas
GVA	:	Gross Value Added
GWP	:	Global Warming Potential
ILO	:	International Labour Organization
ILU	:	Impact of Land Use
IRR	:	Internal Rate of Return
JC	:	Jobs Creation
KPI	:	Key Performance Indicator
LCA	:	Life Cycle Assessment
LCOE	:	Levelised Cost of Energy
NEY	:	Net Energy Yield
NIMBY	:	Not In My Back Yard
NPV	:	Net Present Value
O&M	:	Operation and Management
PBP	:	Payback Period
PED	:	Primary Energy Demand
PM	:	Particulate Matter
SD	:	Sustainable Development
SDG	:	Sustainable Development Goal
SEA	:	Strategic environmental assessment
SEE	:	System Energy Efficiency
SER	:	System Energy Returned
SPB	:	Simple Payback
TLCC	:	Total Life Cycle Cost
USD	:	US Dollar
WACC	:	Weighted Average Cost of Capital
WTP	:	Willingness to Pay

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EXECUTIVE SUMMARY

The aim of D1.5 is to define Sustainability Key Performance Indicators (KPIs) for the scope of the CERESiS project, foreseen to be used as evaluation metrics in WP4. Within this deliverable, a shortlist of customized indicators reflecting the goals of the project was compiled and described.

A literature review of existing KPIs commonly used in the bioenergy sector was initially performed. The indicators were classified into four distinct groups, relating to energy efficiency, environmental impacts, economic viability and social acceptance. Furthermore, custom indicators that focus on soil quality, phytoremediation of biomass and decontamination were proposed and added to the longlist.

After filtering the longlist, a shortlist was composed that contained 11 indicators. The environmental indicators were refined for the scope of the CERESiS project (offtake, biomass contamination, avoided land use change etc).

The KPIs of the shortlist were also matched to relevant SDG goals such as:

- SDG 2: Zero Hunger
- SDG 7: Affordable and Clean Energy
- SDG 9: Industry Innovation and Infrastructure
- SDG 10: Reduced Inequalities
- SDG 11: Sustainable Cities and Communities
- SDG 13: Climate Action

This deliverable will subsequently inform the multicriteria analysis of Task 4.4 and will be used for the assessment of the integrated solution pathways in the DSS developed in Task 4.1.

1 KEY PERFORMANCE INDICATORS CATEGORISATION

1.1 "KPI" Term Definition

A Key Performance Indicator (KPI) is a value which can be compared against an internal target or an external target "benchmarking" to give an indication of performance [1]. That value can relate to data collected or calculated from related processes or activities.

Towards assisting the adoption of performance indicators by companies and institutions, the characteristics of a successful set of KPIs have been described in [1]. According to that, a set of seven principles has been proposed for defining KPIs. In particular, KPIs should be: (a) Measurable, (b) Relevant, (c) Understandable, (d) Reliable/usable, (e) Long term-oriented, (f) Data accessible (based on data and information that can be easily accessed). Furthermore, data and information elaboration for an indicator must be done in a timely manner for informative decision making. Apart from the aforementioned evaluation criteria, an indicator can further be characterized by the following attributes [1]: (a) Identification, (b) Name, (c) Definition, (d) Measurement type, (e) Unit of measure, (f) References and (g) Application level.

1.2 Categorization of KPIs for CERESiS

The Key Performance Indicators were primarily related to financial or operational performance (financial viability, operational cost, investments in community). However, in the last decades, most of the enterprises have become more conscious regarding environmental performance and social responsibility (health and safety), thus increasing their awareness of Sustainable Development (SD) issues. In accordance, the bioenergy industry is seeking a set of indicators to measure sustainability of biofuels and allow comparisons between products, processes, companies, sectors, or countries.

For the biofuel industry, the environmental performance indicators are mostly related to energy efficiency and greenhouse gas mitigation, options which exist in all production steps [1]. While the environmental and economic (investment and operating costs) performance are relatively easy to measure and the indicators are generally well developed and agreed upon, measuring the level of social sustainability of a business or a sector is not an easy task. One of the reasons is that social indicators must consider the many interests of both employees and those of the wider communities to reveal company's social impacts at the local, national and global levels. Furthermore, in social and ethical dimensions of a company activity, many of the variables such as protection of human rights or cultural values are hardly quantifiable and cannot even be defined in physical terms [2]. Nevertheless, the significant concerns for social issues need to be addressed. Therefore, the development of social indicators related to health and safety, labour/management relationship, engagement with local communities, employment, product responsibility, is imperative [1].

Taking into account the KPIs widely used in the biofuel industry and based on the above, various lists of Key Performance Indicators can be compiled that could be used in order to evaluate the sustainability and performance of the respective process. However, in this report focus is given on the energy, environmental, economic and social KPIs, which best describe both the performance and the novelty of the new proposed technology.

2 WORKPLAN TOWARDS THE DEFINITION OF CERESIS KPIS

Defining and quantifying KPIs is a widely accepted way to examine to what extend the expected results have been achieved. The methodology followed by NTUA.HMCS towards the preliminary definition of customized KPIs for the CERESiS concept is presented in Figure 1. Starting from the vast amount of KPIs for the bioenergy sector in general, a "shortlist" of candidate KPIs is compiled. A sufficient quantity and quality of sources facilitates a prudent preliminary selection of the candidate indicators. This list includes KPIs relevant to the project's targets and goals, however already present in relevant reports and standards of the industry.

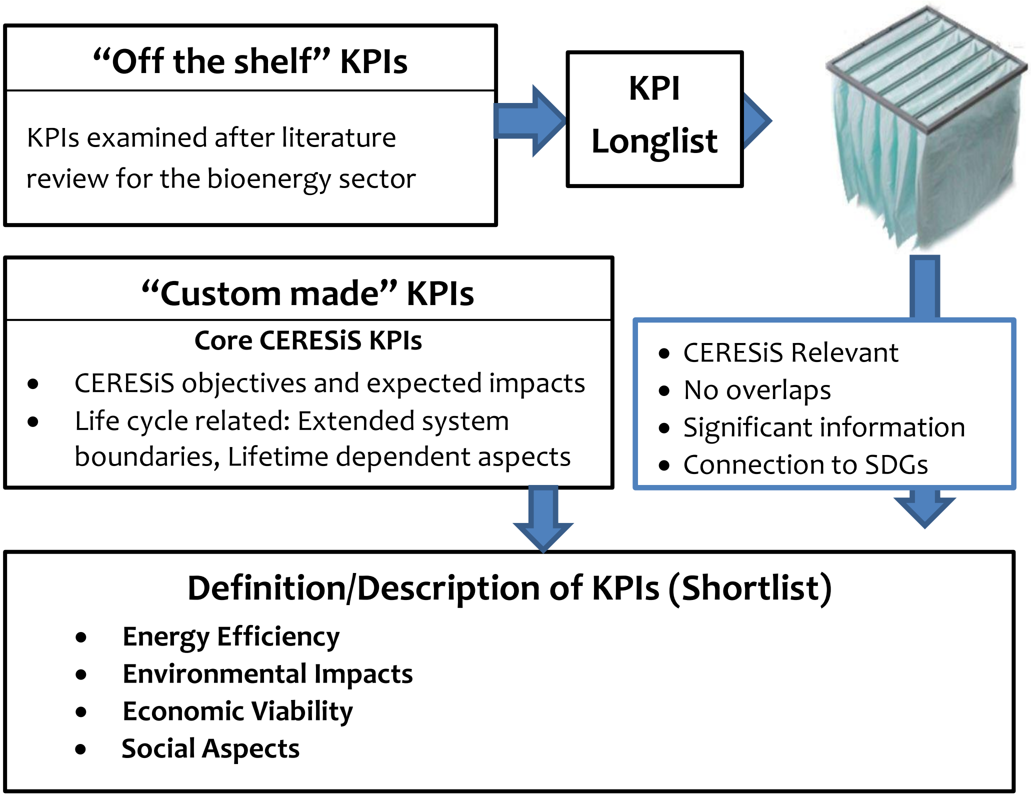

Figure 1 Workflow of CERESiS KPI definition

3 LONGLIST OF KPIS

3.1 Introduction

Classification of KPIs

A basic classification scheme of KPIs is shown below, based on crucial parameters of energy projects, such as the production of liquid biofuels:

Energy efficiency related indicators: Relevant KPIs inform about the net energy yield of a project. They can express absolute values (such as the total energy produced by the project), relative values (e.g., the ratio of energy produced to energy consumed), or time-related values (e.g. the energy payback time). If the total energy required to extract, deliver and consume the raw source is higher than the actual useable energy produced via the project, then the project is likely to yield negative cash flows.

Environmental indicators: Such indicators give information on the impact of a project on the environment (soil, water, atmosphere, climate, natural resources). They seek to quantify how the implementation of a project can affect the ecosystems, by e.g., specifying the amount of GHG emissions, along with the requirement of resources and of land use.

Economic indicators: Economic indicators follow an approach similar to that of energy efficiency indicators, by incorporating the financial aspects associated with a given project. The economic attractiveness of an energy project is fundamental to its viability.

Social indicators: They mainly consist of parameters that capture the impact of the project on human activities. Social sustainability is one of the three pillars for sustainable development. A project is unlikely to proceed unless it satisfies social criteria, such as economic self-sufficiency, equity, health and social cohesion [3].

3.2 Literature Review – KPI longlist

3.2.1 Energy efficiency related indicators

Energy indicators assess the amount of energy required throughout the whole life of a project (including manufacturing, operation and decommission phases) in relation to the useable energy produced by the project in its lifetime. The most common energy indicators are as following:

Longlist of energy indicators

- Primary Energy Demand (PED)

  The amount of Primary Energy (as exist in the form of resources, fossil, nuclear and renewable) required for the final biofuel production. Output of several LCA Impact Assessment methodologies. Measured in MJ-equivalent.[4]

- Energy payback time (EPBT)
  This indicator expresses the time that a project needs to operate to produce the equivalent amount of energy that was required to implement it (manufacturing, construction, decommissioning, Operation and Maintenance (O&M)).

$$EPBT(y) = \frac{Er}{ANEP}$$

  where, E_r (J or Watt hour (Wh)) is the direct and indirect energy required for the project and *ANEP* ((J or Wh)/y) is the Annual Net Energy Production[5]. This result is usually interpreted together with the total life-time duration of the project to illustrate how many years the project is supposed to provide "free" energy, excluding the O&M energy cost [6]. It is considered as one of the main indicators of energy performance.

- Net energy yield (NEY) and Energy Returned On (energy) invested (ERO(E)I)
  The Net Energy Yield (NEY) expresses the difference between the energy resource harvested and is useable for society (over the project's lifetime) and the energy required to extract and provide this energy [7] . Similarly, the EROI is the ratio of the amount of energy harvested to the total amount of energy required to provide it [8]. Both use the life cycle analysis to define their equations' parameters [9].

$$NEY = Ed - Er$$
$$EROI = \frac{Ed}{Er}$$

  where, Ed (Wh or J) represents the energy returned to society, *Er* (Wh or J) is the direct and indirect energy required to provide Ed.

- System Energy Efficiency (SEE) and System Energy Returned (SER). The SER differentiates renewable from non-renewable sources, and it assesses the efficiency of the technologies to use the inherent energy of the non-renewable feedstock. However, the comparison also mixes two different aspects: energy returned and sustainability.

$$SER = \frac{Ed}{(Er + Ef)_{NR}}$$
$$SEE = \frac{Ed}{(Er + Ef)_{tot}}$$

where, Ef (J) is the energy content of the feedstock, and the suffices "NR" and "tot" stands for "non-renewable" and "total", respectively. The inverse of SER represents the intensity of depletion of the stock of nonrenewable resources, while that of SEE is the overall energy resources stock per energy unit returned to society.[10]

- Productivity

  The different types of productivity that can be measured are
  1. Productivity of bioenergy feedstocks by feedstock or by farm/plantation (measured in tonnes/ha per year)
  2. Processing efficiencies by technology and feedstock (measured in MJ/tonne)
  3. Amount of bioenergy end product by mass (measured in tonnes/ha per year), volume or energy content per hectare per year (measured in m^3/ha per year or MJ/ha per year)

This indicator can be applied to bioenergy production. It is mainly focused on resource availability and use efficiencies in bioenergy production, processing and distribution. Productivity is used to measure the output of the production process, per unit of input. In addition, it can be used to measure the efficiency with which inputs are transformed into end products. Furthermore, this indicator focuses on the productivity of the land which is used to produce bioenergy. It can also be used to measure productivity at the farm, regional or national level (taking into account other co-products) and resource use efficiency as well. It must be noted that this indicator focuses on productivity of bioenergy rather than distribution and end-use (however, these can be included where appropriate).[11]

A more efficient use of resources increases availability of resources, reduces negative environmental impacts, and promotes economic sustainability. This indicator also measures local bioenergy production costs in relation to those of domestic and international fossil fuels, other renewable energy sources and international bioenergy, which can help to determine whether local bioenergy is economically viable and competitive at the national level. It is important to mention that the efficiency with which inputs such as water, fertilizers and labour are used in bioenergy production is not directly addressed by this indicator. However, it is indirectly addressed through the final productivity measurement and production costs. [11]

With the increase of productivity inputs are used more efficiently, there is an increased availability of land and other resources, and a reduced burden on the environment. As a result, decreased need of land and inputs reduces costs of production and consequently increases profits. Both aspects are crucial for the national environmental and economic sustainability. The economic viability and competitiveness of bioenergy production that is demonstrated through productivity and cost contribute to its overall sustainability. In addition, productivity and cost, provide an indication of the competitiveness of local bioenergy and the efficiency with which a country uses its resources to provide for its needs. Moreover, they can inform decisions about the scaling up of bioenergy production in a country. Long-term economic sustainability is a function of long-term, steady increases in productivity. Lastly, general rise in agricultural productivity can be reflected in the increased productivity of feedstocks productivity which is closely tied to productivity growth in the bioenergy sector.[11]

- <u>Energy diversity</u>

The description of this indicator is the change in diversity of total primary energy supply due to bioenergy. It is measured in MJ bioenergy per year in the Total Primary Energy Supply (values from 0 to 1).

This indicator concerns bioenergy production and use, and to all bioenergy feedstocks, end uses, and pathways. This indicator refers primarily to the theme of Energy security/Diversification of sources and supply. The UN Development Programme World Energy Assessment defines energy security as “the availability of energy at all times in various forms, in sufficient quantities and at affordable prices without unacceptable or irreversible impact on the environment”. There are several inter-related aspects associated with energy security. These include:

1. Availability – (required energy sources physically available)
2. Accessibility – (delivery of energy supplies taking into account both physical and geopolitical aspects)
3. Adequacy of capacity – (sufficient capacity to produce deliver, distribute and use the energy)
4. Affordability – (acceptable price that energy can be delivered)
5. Environmental sustainability – (avoidance of unacceptable or irreversible impacts)[11]

Given the number of factors considered under this heading, and their complex interrelationships it is not surprising that there is no single indicator for energy security. One approach is to look at how potential interruptions to energy supply can be minimized, using a risk management approach. An important part of that approach is to consider how a diverse set of energy sources can reduce the risks of supply interruption and this indicator focuses on this aspect of energy security. [11]

This indicator provides a metric for measuring changes in diversity of energy supply, and the more diverse the supply, the higher the level of energy security, all other things being equal. Bioenergy can make a contribution to a country's energy security by improving the diversity of supply options and so insulating the country against supply interruptions and price hikes, either by producing and using bioenergy produced indigenously or through imports. The rationale of this indicator is that the contribution of bioenergy to energy security cannot be assessed in isolation, since it depends on the other elements of the supply mix. In addition, a more diversified mix of bioenergy sources provides comfort that this component of the energy mix will itself be more secure. The higher the number of bioenergy sources, the more diversified and secure the mix of supply. [11]

An examination of the diversity of bioenergy sources will give an indication of how robust these supplies are. The analysis shows the role of bioenergy in enhancing energy diversity. The impact on the index is greater in cases where other energy diversity is low. Where biomass has a share that is greater than other sources, an increase in bioenergy's share may actually decrease diversity, according to this measure. However, further consideration may show that having such a high bioenergy contribution may contribute to energy security in other ways and may contribute to other aspects of sustainability. By knowing the sources and volumes of the major components of bioenergy supply, the degree of diversity of the bioenergy component can be assessed. Again, all other things being equal, the more diverse the sources of bioenergy in the total primary energy supply mix, the more sustainable the mix.[11]

- <u>Net energy balance</u>

It is described as the energy ratio of the bioenergy value chain with comparison with other energy sources (energy ratios of feedstock production, processing of feedstock into bioenergy, bioenergy use and life cycle analysis).[11]

This indicator can be applied to bioenergy production, conversion and use, and to all bioenergy feedstocks, end-uses, and pathways and is closely related to the theme of resource availability and use efficiencies. Bioenergy production requires energy as an input at different steps of the value chain. For the primary energy needs of bioenergy production fossil and renewable energy consumption are possible options. The net energy ratio (for example the ratio of energy output to total energy input) is a useful indicator of the relative energy efficiency of a given pathway of bioenergy production and use. It must be mentioned that the more energy consumed during the bioenergy lifecycle, the less energy is available to meet other energy needs. Efficient use of energy is essential for improving energy security and for optimizing the use of available natural resources. However, energy inputs to the bioenergy production process can possibly come from hydrocarbons, and as a result, a high net energy ratio will indicate efficient use of these non-renewable resources. [11]

If the net energy ratio has a value which is greater than one for the combined production, processing and use of a given bioenergy feedstock indicates that its production is sustainable from an energy perspective. That means that the quantity of energy that the biofuel can provide is higher than the amount of energy needed for its production. In other cases, the net energy balance will represent the extent to which the bioenergy replaces fossil fuels, which is another clear indication of its contribution to sustainable development. In conclusion, taking into account the above indicator provides a basis for identifying the most energy efficient ways to produce bioenergy among a given set of options and may be used to select appropriate feedstocks, technologies and practices. [11]

- <u>Change in consumption of fossil fuel and traditional biomass</u>
  Categories of this indicator are:
  1. Substitution of fossil fuels with domestic bioenergy measured by energy content (MJ per year and/or MW per year) and in annual savings of convertible currency from reduced purchases of fossil fuels (USD per year)
  2. Substitution of traditional use of biomass with modern domestic bioenergy measured by energy content. (MJ per year and/or MW per year)

The consumption of locally produced biomass for bioenergy can displace the use of fossil fuels, and traditional use of biomass for energy as well, which would have significant positive impacts on the economic development and energy security of a country or region. With the reduction of the consumption of imported fossil fuels, savings can be brought about in convertible currency. For low-income, developing countries, these savings could lead to increases in reserves of convertible currencies. It is important to note that, the level of convertible currency reserves is relevant to sustainable economic development of many countries, particularly low-income countries, since it provides the means to purchase imports and to protect the value of their currency.

Moreover, public savings from avoided fossil imports could be diverted to promote development locally through investments in infrastructure, education, sanitation, and other essential services. However, the production of bioenergy may be either more or less expensive than importing fossil fuel, a factor which mostly depends on the country in context. As a result, these relative production costs, investment costs, and the cost of building the infrastructure necessary for a vibrant bioenergy sector should be considered when calculating the effects on savings in convertible currency. Replacing traditional use of biomass with modern bioenergy will bring a wide range of benefits for social and economic development, particularly in rural areas.[11]

Lastly, this indicator gives an important overview of the extent and pace of a transition to modern bioenergy and, as a result, informs the overall assessment of the contribution of bioenergy to sustainable development at the national level.[12]

- Capacity and flexibility of use of bioenergy
    1. Ratio of capacity for using bioenergy compared with actual use for each significant utilization route
    2. Ratio of flexible capacity which can use either bioenergy or other fuel sources to total capacity

It must be noted that, unused or flexible capacity in using bioenergy contributes to overall energy security and can be considered as an aim for infrastructure development for bioenergy use. A flexible bioenergy system helps to reduce the risks and further bring down operating costs. Furthermore, it provides useful information on the flexibility of the demand side to rapidly increase or diminish fuel or feedstock consumption and therefore its ability to respond to unexpected shortages of bioenergy and bioenergy feedstock due to adverse conditions or political implications. In addition, a high degree of flexibility in the use of bioenergy can translate into a rapid increase of bioenergy consumption under favorable economic conditions.[11]

3.2.2 Environmental indicators

As stated in Rettenmaier et al.[13], biofuels and bioproducts, and bioenergy in general "are not environmentally friendly per se, just because biomass is renewable." As a result, specific indicators and methods are needed for the description of impacts. In the document "Bioenergy Environmental Impact Analysis (BIAS)", Fritsche et al.[14] developed a study of the influence of biomass production on the environment. In this document four areas of concern were presented, alongside with potential impacts, and possible indicators to measure them. These areas are:

1. Biodiversity (losses of biodiversity on managed land and changes at the landscape level)
2. Water (decreased water availability for biomass production and groundwater depletion)
3. Soil (soil erosion as well as carbon and nutrient loss)
4. Climate change (reduction of GHG emissions)

In addition, an extensive evaluation of sustainability indicators in the field of bioenergy production was highlighted by the Global Bioenergy Partnership[11]. This document addresses various indicators with a short description and a methodological factsheet for their analysis. In GBEP, environmental sustainability of the bioenergy supply can be clarified by the evaluation of the following parameters:

1. lifecycle GHG emissions
2. soil quality, harvest levels of wood resources
3. emissions of non-GHG air pollutants, including air toxins
4. water use and efficiency, water quality, biological diversity in the landscape
5. land use change related to bioenergy feedstock production.

Research more centered on the definition of local scale and farm/firm-level indicators can also be depicted in the literature. A particular indicator could be, in fact, designated only for a specific scale of analysis, as it could cause misunderstandings at different levels. Such examples include how GHG emissions or land use change seem to be difficult tasks to quantify at the farm level. In contrast, biodiversity loss is often easily measured at the small-scale level unless a landscape evaluation is needed. [15]

Environmental assessment techniques able to determine the impact of biomass supply chains include:

1. product carbon footprints
2. life cycle assessment (LCA)
3. eco-audit
4. environmental impact assessment (EIA)
5. strategic environmental assessment (SEA)[13]

Each method presents pros and cons; for example, LCA and SEA are more useful for large-scale projects, and on the other hands eco-audits and EIA could be properly applied for specific medium- to small-scale contexts.

Biofuel and biomass-to-liquid (BTL) impact analysis have been examined in several studies. Sustainability indicators for this matter have been reported for both agricultural and forested land. The environmental effect that biofuels have in an agricultural system can be measured as potential losses of biodiversity (ie, in biological terms and at the landscape level). Liu et al. [16] reported introgression and contamination by aggressive genotypes as relevant risks from a genetic point of view. Additional issues can be depicted at the species level. Furthermore, the authors indicated habitats experiencing pollution and degradation risk hazards such as native extinction and bioinvasion. Fragmentation of agricultural land and species substitution usually damage landscapes with a reduction of the edge effect, negatively impacting habitats [17].

Increased water consumption is an additional issue to consider with respect to food-crop production. Some studies that focused on water related issues are:

1. Faist Emmenegger et al.[18] considered irrigation efficiencies, water scarcity, and feedstock type to develop an LCA focused on biofuel production.
2. Chiu et al. [19] studied the water consumption impact assessment for corn-based bioethanol production in a case study in North America, focusing on the potential optimization of consumption at the refinery level.
3. Msangi et al. [20] considered a potential trade-off between food and fuel production. Focusing on the impact on water, the authors stressed how the expansion of biofuels would increase the stress on regional water supplies only marginally, which could cause problems in areas facing water scarcity.
4. Sunde et al. [21]discussed the impact of BTL focusing on the forest sector. They stated that despite a particular advantage due to GHG reduction, wood based BTL may increase eutrophication and acidification and augment ozone depletion and toxicity.
5. Ortiz et al. [22] studied the reduction of soil organic carbon accumulation. As reported in that study, a negative effect is caused by the stump removal from top and branch extraction. Additionally, to the decline of the organic component and the consequent reduction of fertility, a compaction risk is also a threat in biofuel production from forest biomass [23],[24]. In fact, extraction of residues generally requires a high mechanization level that can cause more problems to forest terrain due to technological requirements.

Most of the above environmental impacts of biofuel production reported for the agricultural and forest sectors can also be used for the theme of biomass-to-energy. A few differences could be mentioned in the case of cultivated crops for bioenergy in dedicated land. In fact, farming practices should require different factors of production of biofuel than those of bioenergy. This distinction is important because of field phases in which input can vary. In most cases, larger quantities of water and fertilizer consumption is required for biofuel production compared to bioenergy production (for example for short rotation coppices). It must be noted that the harvesting phase could reveal diverse ecological impacts according to morphological and soil-based variability of the site as well as the specific machinery employed. However, a systemic comparison between biofuel and bioenergy, such as LCA, Energy/Exergy analysis, or Ecological footprint analysis for specific case studies was not found after literature review.[15]

To avoid the negative effect of biomass production from an environmental viewpoint, some authors emphasized on constraints and good practices to accomplish.

1. Demirbas,[25] mentioned that high carbon-stock land or exploitation of protected areas should be avoided
2. Koh et al.[17] suggested the expansion of agro-forestry and fragmented areas close to biofuel/bioenergy crop cultivation, wildlife-friendly farming, and technical limitations (for example due to slope, soil parameters, etc.; [23])

Lastly, it is worth noting how the biomass supply for bioenergy and biorefining could also have potential neutral or positive impacts on the environment. Meller et al. [26]reported a review on negative, neutral, and positive impacts of biomass from different land use types focusing on species biodiversity (such as butterflies and earthworms in arable crops, birds and arthropods in grassland biomass, and plants, butterflies, birds, and winged invertebrates in bioenergy plantations) that were positively impacted. Similarly, Holland et al. [27] focused on the impact of second-generation bioenergy crops in arable land, grasslands, and forests. For the cases of Miscanthus, short rotation coppices, and short rotation forestry, the authors concluded that positive impacts mainly concentrated in arable (and grass-) land in terms of water and soil quality, pollination, disease and pest control, and hazard regulation. In addition, extraction of fine woody debris could be particularly important for fire risk reduction due to changes in climatic conditions, vegetation characteristics, and pest diseases.

Longlist of environmental indicators

Environmental indicators make use of parameters that characterize the impact of an energy project regarding the land, the atmosphere, the resources availability, the humans and the ecosystem. They include necessary but not sufficient criteria for the implementation of a project. Some of the most useful environmental KPIs are presented below:

- Global warming potential (GWP). This indicator represents the effect of different GHGs to climate change, taking as reference the GWP of CO2. The general relationship for calculating the GWP (expressed in g $CO_{2\text{-}eq}$ / J or Wh) of an energy project is the following:

$$GWP = \sum_{k}^{K} GWP_k \cdot B_k$$

where, K is the total number of GHGs emitted from the project, GWP_k is the global warming potential of GHG k and B_k represents the emissions of the GHG k, per unit of energy produced (expressed in g / J or Wh)[28]

- Land-use changes and requirement.
  This indicator shows the amount of land required per unit of energy produced (net energy) in m^2 (Wh or J) can be quantified. The analysis can consider the land used for the energy production plant, but also for the fuel extraction when appropriate. Fritsche et al. proposed an interesting comparative approach for determining the "land footprint" of different energy sources considering direct and indirect impact[29]. The impact of land use (ILU expressed in $m^2 \cdot y$ / J or Wh) of a plant is calculated as following:

$$\mathrm{ILU} = \mathrm{LA} \cdot t_{LA}$$

  where, LA (m^2/J or Wh) is the total land area required for the construction and operation of the project per unit of energy produced and t_{LA} is the amount of time that the land area is occupied by the project (y). [30]

- Soil quality
  This indicator is related to the percentage of land for which soil quality is maintained or in other cases improved out of total land on which bioenergy feedstock is cultivated or harvested (in terms of soil organic carbon). The indicator applies to bioenergy production from all bioenergy feedstocks.

  Soils are an important factor of the productive capacity of the land. Soil degradation (mostly caused by climatic factors, poor agricultural practices and their interaction), can lower the productive capacity of the land. So, appropriate agricultural and soil management practices can help to maintain/improve soil quality, and therefore have a positive effect on the productive capacity of the land. In addition, the development and use of technologies for soil conservation and management play a crucial role. The five key factors that contribute to soil degradation are:

  1. loss of soil organic matter which can cause decreased carbon and soil fertility
  2. soil erosion which leads to soil loss (primarily fertile topsoil)
  3. accumulation in soils of mineral salts (salinization) from irrigation water and/or inadequate drainage, with possible adverse effects on plant growth
  4. soil compaction, reduced water flow and storage, limited root growth
  5. loss of plant nutrients (for example through intensive harvest)[11]

  Organic matter within the soil serves several functions:

  - maintain nutrient capital, providing plant-available nutrients (nitrogen, phosphorus, sulphur, iron)
  - improvement of soil structure and minimization of erosion
  - aid water infiltration and retention

  This indicator aims to monitor the influence of bioenergy production on soil quality. The production is considered more sustainable when the percentage of land is used for producing bioenergy feedstocks where soil quality is maintained or increased is high. In cases where the percentage is low or declines, it may indicate a need to review policy and practice in order to identify ways of making bioenergy feedstock production more sustainable. For instance, if soil organic carbon levels decline, it is useful to investigate the extent to which extraction of primary agricultural or forestry residues for bioenergy production could have been responsible.[11]

- <u>Harvest levels of wood resources</u>

  This indicator is related to the annual harvest of wood resources by volume and as a percentage of net growth or sustained yield, and the percentage of the annual harvest used for bioenergy. It is measured in (m^3/ha/year), (tonnes/ha/year), (m^3/year or tonnes/year). [11]

  The indicator applies to bioenergy production from wood resources and forestry residues. It aims to monitor the harvest of trees, wood resources as well as the removal of wood harvest residues for bioenergy. Forestry practices that are considered unsustainable may disrupt nutrient cycles and deplete soil of organic matter, which has negative impacts on both continued wood production and for the moisture holding capacity of the soil and overall hydrological function of the land as well. [11]

  Moreover, this indicator is able to assess whether forests are being harvested beyond their ability to renew themselves and how much of the harvested wood and harvest residues are being used for energy purposes. Monitoring the volume of wood and non-wood forest products annually removed relative to the amount which could be removed sustainably provides an indication of a forest's ability to provide a continuing supply of forest products. As a result, this provides a basis for identifying the degree to which bioenergy production is part of sound forest management. The use of biomass for bioenergy creates a demand for woody harvest residues, such as low-quality trees, branches, and stumps. These residues contain nutrients that would otherwise contribute to forest soil nutrient cycling. [11]

- <u>Emission of non-GHG air pollutants</u>

  The emissions of non-GHG air pollutants (emissions of $PM_{2.5}$, PM_{10}, NO_x, SO_2 and other pollutants), including air toxics, from

  1. bioenergy feedstock production (mg/ha)
  2. processing, (mg/MJ)
  3. transport of feedstocks, intermediate products and end products use (mg/MJ)

  This is indicator is made up of four aspects:

  1. Field work with agricultural equipment in bioenergy feedstock productions emits non-GHG pollutants. Moreover, field burning, if

performed, can be a significant component of the pollutants affecting air quality within the lifecycle of bioenergy production. The extent of practice of land clearing by field burning within a country can be regarded as information about the performance of biomass production in the country with regard to air quality. The lower the level of land clearing and crop burning, the lower the negative impact on air quality and the better the performance against this criterion.

2. The processing facilities for the production of bioenergy can contribute significantly to the whole lifecycle balance of non-GHG pollutants. Bioenergy production and processing can involve air pollutant emissions. Low-emission conversion excludes this potentially negative impact of bioenergy production. Monitoring emissions from bioenergy production and processing can support the demonstration and uptake of best available technologies.
3. Transportation plays a major role in releasing air pollutants Since bioenergy feedstocks have a low density, the requirement to transport these feedstocks to processing plants can result in an increase in transportation. As such, transportation of bioenergy feedstocks and of bioenergy products has the potential to impact air quality. Short transportation distances reduce potentially negative impacts of bioenergy production. Measurement of emissions from this phase of the lifecycle could inform decisions on location of processing plants and choice of transportation method and fuel use
4. The use of bioenergy is a major phase in the whole life-cycle balance of non-GHG pollutants. In most countries, energy use and transport cause the major portion of national pollution inventories. Tailpipe pollution from transport is the dominant factor affecting air quality in most cities of the world. The use of biofuels can reduce non-GHG air pollution relative to fossil fuels with the decrease in particulate matter being quite significant. Similarly, low efficient traditional bioenergy (e.g., fuelwood) leads to significant air pollution in many rural areas, especially in developing countries. A significant shift from fossil fuel to biofuel is likely to cause changes concerning urban air quality. Some changes might be positive, some might be adverse. This indicator shall describe such changes. [11]

This indicator will help to identify whether the production, conversion and use of bioenergy are weak or strong contributors to air pollution. If applied as a comparison with fossil fuels, specific advantages or disadvantages per energy unit will be expressed.[11]

- Water quality

This indicator refers to two categories:

1. Pollutant loadings to waterways and bodies of water attributable to fertilizer and pesticide application for bioenergy feedstock production and expressed as a percentage of pollutant loadings from total agricultural production in the watershed. Measured in nitrogen (N) and phosphorus (P)

loadings annually from fertilizer and pesticide active ingredient loadings attributable to bioenergy feedstock production (per watershed area):
   - in kg of N, P and active ingredient per ha per year
   - as percentages of total N, P and pesticide active ingredient loadings from agriculture in the watershed
2. Pollutant loadings to waterways and bodies of water attributable to bioenergy processing effluents and expressed as a percentage of pollutant loadings from total agricultural processing effluents in the watershed. Measured in:
   - pollutant loadings attributable to bioenergy processing effluent: pollutant levels in bioenergy processing effluents in mg/l (for pollutant concentrations and biochemical and chemical oxygen demand – BOD and COD), and (if also measured) °C (for temperature), μS/m (for electrical conductivity) and pH
   - total annual pollutant loadings in kg/year or (per watershed area) in kg/ha/year
   - as a percentage of total pollutant loadings from agricultural processing in the watershed[11]

The indicator applies to production of those bioenergy feedstocks that use fertilizer (including manure) and pesticide, and to effluents from processing plants for all bioenergy feedstocks, end-uses and pathways.[11]

This indicator is primarily related to the theme of water availability, use efficiency and quality. Its main focus is to measure and monitor the impact of bioenergy feedstock production and processing on water quality. As an example, nitrogen and phosphorous fertilizers and pesticide used for bioenergy feedstock production and effluents from bioenergy processing facilities might increase the pollution of waterways and bodies of water such that water quality may suffer significant decline

<u>Nitrogen</u> is considered a crucial nutrient for plants and animals. Terrestrial ecosystems and headwater streams possess the ability to capture it, through fixation, and to reduce it to N_2 gas through the processes of nitrification and de-nitrification. As a result, Nitrogen cycling, and retention is one of the most important functions of ecosystems. When loads of N from fertilizer, septic tanks, and atmospheric deposition exceed the capacity of terrestrial systems to hold and cycle it, then the excess may enter surface waters, where it may create harmful effects as it moves downstream to coastal ecosystems.

<u>Phosphorus</u> is a critical nutrient for all forms of life, but similarly to nitrogen, phosphorus that enters the environment may exceed the capacity of the terrestrial ecosystem. This excess P may enter lakes and streams. Because phosphate is often the limiting nutrient in these waterways and bodies of water, an excess may contribute to algal blooms and exponential growth of cyano bacteria, which cause taste and odour problems and deplete oxygen needed by aquatic organisms.

Effluents from processing plants: Wastewater from bioenergy production facilities is potentially high in nitrogen and phosphorus that contribute to biochemical oxygen demand (BOD). It must be mentioned that discharge of high-BOD water to waterways and bodies of water can cause problems because decomposition can consume all of the dissolved oxygen, which results in suffocating aquatic animals. Furthermore, additional pollutants in effluents from bioenergy processing plants that could affect water quality will vary as a function of the feedstock and process. More specifically, some processing effluents may be acidic, while others may be alkaline. Changes in pH, both acidic and alkaline, can negatively affect aquatic life and use of the water, but the effects of effluent will depend on properties of the watershed. [11]

- Biological diversity and landscape
  The categories concerning this indicator are
  1. Area and percentage of nationally recognized areas of high biodiversity value or critical ecosystems converted to bioenergy production
  2. Area and percentage of the land used for bioenergy production where nationally recognized invasive species, by risk category, are cultivated
  3. Area and percentage of the land used for bioenergy production where nationally recognized conservation methods are used

Measurement Units: Absolute areas in hectares or km^2 for each component and for total area used for bioenergy production. In addition, percentages of bioenergy production area can be calculated from these and given either separately for each relevant category or as a combined total across such categories.[11]

This indicator is related mainly to the theme of biological diversity. Bioenergy production can affect biological diversity negatively. Conversion of land within areas recognized nationally as important for biodiversity and critical ecosystems to bioenergy feedstock production may have negative impacts on biodiversity. Moreover, another risk is the potential of some species cultivated as bioenergy feedstocks to become invasive and displace native species. Specifically, many agricultural and forest management practices involved in feedstock production can have adverse impacts on biodiversity, ranging from direct mortality of invertebrates and their predators caused by pesticide use to reduction in resources available to pollinators and suppression of soil fauna. However, others can limit adverse impacts and may have positive impacts on biodiversity. Identification and monitoring of areas converted for bioenergy production and of potentially invasive species used as bioenergy feedstocks are the first steps towards preventing loss of biodiversity. In conclusion, the employment of nationally recognized conservation methods (aimed at limiting adverse impacts on biodiversity from agriculture and forestry) in and around biofuel production areas can help reduce negative and promote positive impacts on biodiversity.[11]

3.2.3 Economic indicators

The economic evaluations of biomass supply chain developed for the local (eg, farm and firm level) to international scale are mainly focused on the traditional accounting framework and employment indicators. Studies have introduced additional parameters to be evaluated, such as indicators related to environmental or ecological economics, features linked to green jobs, land use, or substituted market competition effects, and poverty rates and income equality.

The basic economic feasibility of bioenergy and biofuel production and their associated impacts should be computed by means of traditional financial indicators. Classic examples of such indicators include net present value (NPV), the internal rate of return (IRR), and the payback period (PBP; JRC-IET, 2015). These indexes can be calculated for the whole chain, or more appropriately, for a particular step (eg, feedstock production level, in the implementation and management of district heating plant, etc.). The fundamental variables to compute the above parameters are costs and benefits (or revenues in financial terms). Costs are the initial expenses and running outlay (operational and maintenance), whereas revenues are identified in incentives, avoided cost (eg, for reduction of energy expenses related to fossil fuels), or income due to the selling of biomass or its derivatives, such as bioenergy. NPV is the sum of discounted annual savings for the investment.

In its simpler form, the PBP represents the period of time needed to recoup the expenses of an investment. The last examined indicator is the IRR, which gives an idea of the investment's profitability. In general, the IRR corresponds to the discount rate that makes the NPV equal to 0. All of the above metrics present advantages and disadvantages and should be used together for a comprehensive evaluation of the investments.

A literature review conducted by Van Dam et al. [31] defined a list of specific potential economic impacts due to first- and second-generation biomass feedstock. The work mainly stresses positive impacts, i.e, the reduction of poverty, the contribution to the economy (for which income improvement and an investment's cash flow can be included), employment advantages, and income equality. If the profitability of a business venture of biomass production appears easily valuable in financial terms, the analysis of negative and positive economic effects becomes more complicated at different spatial and temporal scales.

Widespread interest has arisen to examine the influence of bioenergy and biofuel production on agricultural land and food crop prices. This potential conflict can be identified for both the exploitation of the resource (eg, food versus energy) and the competition of primary resources (inputs) necessary for the realization of bioenergy (eg, surface of arable land). Van Dam et al.[31] reported the relevance of competition in biomass production on agricultural land prices. Ignaciuk et al.[32] developed a partial equilibrium model that correlates the effects of energy policies with the potential level of GHG emissions, land use, and bioenergy/food crop prices. The work focused on the substitution effect, which maximizes the economic surplus of producers and consumers. The results show a direct proportionality among agro-energy and food crop prices.

Johansson and Azar [33] evaluated the effect of substitution between food and nonfood crops in the presence of agro-energy policies for the US agricultural sector. This research introduced the importance of different levels of soil fertility to estimate the increase of marginal area demand for biofuel production. The competition between agribusiness and agro-energy was analyzed on a global scale by Pruyt and De Sitter [34] with a System Dynamics model able to highlight the positive and negative impacts on the economic components due to the transfer of resources between different sectors. Among various conclusions, the authors assert how the competition between food and nonfood products can be expected to decrease with the passage from first to second-generation biofuels but that the first-generation production is a necessary step. A forecast of potential bioenergy production based on dedicated crops was developed by Erb et al. [35] considering plant productivity and constraints to maintain biodiversity. The authors stress how with the introduction of those limitations, the prediction of bioenergy production decreased approximately 45%.

A possible contrast exists with bioenergy in the forest sector with regard to wood processing industries, particularly in primary processing (sawmills). We notice how the use of sawmill residues for energy production may create a potential conflict with alternative uses, such as the fabrication of panels. Schwarzbauer and Stern [36] analyzed this conflict using a simulation model, (Forst- und Holzwirtshaft - FOHOW), implemented for Austrian forestry. This research shows that in the short term, the increase of residue prices can induce a loss of profit for the sawmills (due to higher prices of roundwood and substantial stability in the price of residues); however, these losses may decrease until they reach a positive profit in the medium term (to 2020). The same authors estimate a competition of resources in terms of cost and availability, including the use of woodchips for the production of paper or panels. Using the Material Flow Analysis technique, similar conclusions were reached in Ackom et al. [37] for the production of pellets and ethanol in Canada and in Trømborg and Solberg [38] for the production of cellulose pulp in Norway. Scant studies reported on the potential competition of innovative biomass for energy versus traditional assortments at forest enterprises at the local market level. Manley and Richardson [39] examined different forest management systems, including conventional organizations for managing softwood, hardwood, and mixed wood forests for the production of multiple products with an emphasis on bioenergy. The potential economic trade-off between two forest bioenergy products was investigated in Sacchelli et al. [40]. In this work, the substitution effect of firewood and woodchips was defined at different spatial levels considering parameters such as Break-Even Prices of the assortments and elasticity, stressing the importance of vegetation and mechanization variables for trade-off analysis.

All of the abovementioned substitution effects and competition could also have indirect effects on local and global markets. Indirect effects of biomass for bioenergy and biorefinery could be properly quantified using an Input/Output (I/O) matrix that enables analysis of interdependence and economic flow among entities (e.g., satellite activities) and for different scales. Cruz et al. [41] applied an I/O matrix to a bioenergy supply chain, in which a control theory-based optimization of policies was developed. By means of the

I/O technique, Yazan et al. [42] evaluated sunflower cultivation impacts on the economic and environmental performance of bioenergy production chains in Apulia, Italy.

As demonstrated in several case studies, employment created by biomass supply can generate added value in bioenergy chains and local economies. New job opportunities (so-called “green jobs”) are related to different steps of bioenergy and biofuel production from the field phase to selling and plant maintenance. A review of potential opportunities for employment was developed by Domac et al. [43]. The authors suggested that despite several differences between developing and developed countries, bioenergy in both cases has the greatest potential in job creation with respect to other renewable energies. In particular, for EU countries, Domac et al. [43] indicated that the bioenergy contribution for job opportunities depends on local conditions, such as demographic and economic variables, but showed the greatest potential for positive indirect economic effects. For EU Member States, it was indicated that a distribution of 273,150 workers in the solid biomass sector and 151,200 for biofuels, with an annual growth of approximately 8%.[15] In the United States, a study of green jobs related to renewable energy was developed. This study highlighted the strong importance of policies that were able to create approximately 50,000 work units in the biofuel/bioenergy sector in the period 2003-2010. According to the Environment and Energy Study Institute (EESI) [44], for the period 2012-2013 in the United States, more than 15,500 direct jobs and a total of 152,000 employed units were created in the industry supporting the biomass sector. EESI also indicated a total of 852,056 new jobs in the United States, including direct and indirect jobs in supplier chains for renewable fuel production.

The need to introduce environmental and nonmarket goods and services generally in monetary evaluations led economists to form new methods and tools to quantify these values. The appraisal of economic social utility takes a consolidated form in the environmental economics (EE) or in the so-called cost-benefit analysis, which is “an analytical tool to be used to appraise an investment decision to assess the welfare change attributable to it”[45]. For energy EE applications to biomass, several methods were used to translate the social utility function to monetary terms. For example, Susaeta et al. [46]used the contingent valuation method to define the willingness to pay (WTP) of Arkansas, Florida, and Virginia inhabitants for bioelectricity.

Economic indicators integrate parameters such as costs (Co), revenues (Ci), energy output and discount rate (r) of the featured project. The differences lay in the way the indicators are expressed, for example: a rate, a ratio, a number of years, a difference, etc. They indicate utility for developing the economic scenario and provide results in different angles.

Longlist for economic indicators

- Total Life-Cycle Cost (TLCC) represents the total expenditure over the whole project’s life and discounts this amount to a present value. It can include taxes if needed, and the equation must be adjusted according to the relevant tax system in operation.

$$\mathrm{TLCC} = \mathrm{CC} + \mathrm{OC} + \mathrm{MC} + \mathrm{FC} - \mathrm{SV} - \mathrm{BP}$$

where CC is the initial capital cost, OC is the operating cost, MC is the maintenance cost, FC is the feedstock costs, SV is the salvage value, and BP represents the by-product credits[47].

- Net Present Value (NPV). The discounted cash flow (DCF) valuation approach provides a basis for assessing the cash flows of a project. The total lifetime cash flows are discounted to the present or to a defined base year. The NPV analysis brings together the TLCC and the total lifetime revenues (both discounted to base year)

$$NPV\ (Euros) = -CF_0 + \sum_{t=1}^{N} \frac{CF_t}{(1+r)^t}$$

where, N is the lifetime duration of the investment, CF_0 is the cash flow in year 0, CF_t are the free cash flows of period t, namely the difference between costs and revenues including taxes, depreciation, etc. The parameter r is the real discount rate

- Simple Payback (SPB) and Discounted Payback (DPB) period. The simple and discounted payback period indicators specify the length of time required for the cumulative revenues to be equal to the cumulative costs, i.e., the required length time for an investment to reach its breakeven point [48].

$$SPB\ (years): \sum_{t=1}^{SPB} Btot,t = \sum_{t=1}^{SPB} Ctot,t$$

$$DPB\ (years): \sum_{t=1}^{DPB} \frac{Btot,t}{(1+r)^t} = \sum_{t=1}^{DPB} \frac{Ctot,t}{(1+r)^t}$$

B_{tot} are the total revenues
C_{tot} are the total costs
r is the real discount rate
These indicators inform the investor about the amount of time the investment is at risk. It is often used with the financial risk exposure.

- Weighted Average Cost of Capital (WACC) represents the cost that a company must pay to raise the capital required for the implementation of the project. Basically, this indicator gives a view on the financial aspect by giving the average rate of return that a company must generate to satisfy its investors (shareholders and debtholders). Hence, it is usually used as the corporate hurdle discount rate in the project cash flow calculations. [30]
It is calculated by the following expression:

$$WACC = r_{eq} \cdot \frac{E_c}{V} + r_d \cdot \frac{D}{V} \cdot (1-T)$$

E_c is the market value of equity
D is the market value of debt
$V = E_c + D$

r_{eq} denotes the return on equity
r_d is the interest rate on debt
T is the corporate tax rate

- Benefits to Costs Ratio (BCR) is an indicator composed of the ratio between the discounted benefits and costs over a period of time. It could be said that BCR is the corresponding economic indicator of the EROI [30]
  The formula for this indicator is:

$$BCR = \frac{\sum_{t=1}^{LT} \frac{B_{tot,t}}{(1+r)^t}}{\sum_{t=1}^{LT} \frac{C_{tot,t}}{(1+r)^t}}$$

  B_{tot} are the total revenues
  C_{tot} are the total costs
  r is the real discount rate

- Internal Rate of Return (IRR) is a common metric used in capital budgeting to evaluate the profitability of potential investments and it is defined as the discount rate that sets NPV of an investment equal to zero. [30]

$$IRR(\%): \sum_{t=1}^{LT} \frac{B_{tot,t} - C_{tot,t}}{(1+IRR)^t} = 0$$

  B_{tot} are the total revenues
  C_{tot} are the total costs

  Levelised Cost of (Bio) Energy (LCOE) (from biofuels) is an indicator that is widely used to compare specifically energy generation technologies in term of their cost competitiveness [86].

$$LCOE\left(\frac{Euros}{Wh}\right) = \frac{\sum_{t=1}^{LT} \frac{C_{tot,t}}{(1+r)^t}}{\sum_{t=1}^{LT} \frac{ANEP_{biofuels}}{(1+r)^t}}$$

  Where $C_{tot,t}$ is the total cost in the year t, $ANEP_{biofuels}$ is the bio-energy produced from biofuels and r is the real discount rate.

- Gross value added. It describes the gross value added per unit of bioenergy produced and as a percentage of gross domestic product and its measurement units are Euros/MJ and percentage. This indicator is primarily related to the theme of Economic development, which is defined by the World Bank as qualitative change and restructuring in a country's economy in connection with technological and social progress. One of the most commonly used indicators of economic development is Gross Domestic Product (GDP) per capita, which measures the level of total economic output of a country relative to its population and to a degree, reflects the standard of living of the country's population. Gross value added (GVA) is defined as the value of output less the value of intermediate consumption and is a measure of the contribution to GDP made by an individual producer, industry or sector. GVA provides a monetary value for the amount of goods and services that have been produced, less the cost of all inputs and raw materials that are directly attributable to that production.

Gross value added = Total output value - Intermediate inputs [11]

- Productivity: A KPI also mentioned in the energy section. It takes into account the overall economic efficiency of the production which helps capture the overall efficiency of use of all inputs. This KPI refers to the production cost per unit of bioenergy (measured in Euros/MJ)

3.2.4 Social indicators

The implementation of biomass supply chains for the production of bioenergy and/or biofuels is often thwarted by public and local stakeholder opposition, despite potential technical-economic and normative feasibility. This opposition is generally known as the NIMBY (not in my backyard) effect. The NIMBY effect can be categorized as a consequence of perceived negative impacts due to biomass chains, including environmental, economic, and social aspects. However, in the NIMBY phenomenon, the local population seems to focus its attention on the social consequences of biofuel production for both intra- and intergenerational justice. In this case, the first impacts to be examined are the effects on people's health. Focusing on the supply side of the chain and based on a literature review of Holland et al. [27], some positive health-related impacts are outlined for the substitution of traditional crops on arable lands. Regulating services of arable land, marginal land, or forest replacement (climate change, hazard, noise, pest and disease, water/air quality) indirectly associated with health effects are also mainly revealed as positive impacts. On the other hand, the negative impacts include the reduction of natural area or an excess of nutrients, sediment, or chemicals due to energy crop cultivation. Moreover, impaired potential recreational and touristic sites with negative consequences on leisure, tourism, religious, and spiritual activities; and human health ecosystem services [49]. In addition, potential traffic annoyance caused by biomass transport could be depicted as an increase of noise and for perception of health impairments, risk of traffic accidents[50] .

Several authors focused on the risk of decreased food availability, access, and distribution if energy crops are produced on competing agricultural land [31]. For example, a particular impact on food security and food stability could be possibly connected to biofuel production in both industrialized and developing countries [51]. Other conclusions are revealed in Msangi et al. [20], who demonstrated how a "food-versus-fuel" trade-off would likely increase the number of malnourished people.

Even though landscape variability was indicated as having a latent effect on biodiversity, some authors introduced the visual landscape changes as a social impact due to the potential detriment of cultural aspects and heritage for tourists or inhabitants [52]. Furthermore, losses of both property rights and the right of use of agro-forestry areas were defined as possible additional negative impacts of the biomass supply chain in developing regions. [53]

Indirect economic benefits generally improve the social condition, particularly at a local scale. Access to health and educational services, no child labor, and working hour limitations are reported as positive consequences of biofuel production, particularly if certification schemes are present [54]. These advantages can be observed with more prominence for developing countries.

Social indicators are usually expressed through statistical data (such as number of jobs-years per GWh), expressions involving multiple parameters, or semi-quantitatively, by rating a specific project in terms of the social indicator on an ordinal scale.

Long list of social KPIs

- Jobs creation (direct and indirect). Jobs creation demonstrates the potential for creation of jobs associated with the project, from construction to decommissioning, including O&M. Direct employment refers to the jobs created directly by core activities of the energy generation project without accounting for the intermediate inputs (such as the supply of materials and financial services) necessary to manufacture the equipment, construct and operate the plant, which are covered by upstream industries supplying and supporting the core activities (indirect employment) [55]. The jobs creation indicator is measured in jobs-years per Wh or Joule [56], according to the following expression:

$$\mathrm{JC} = \frac{\sum_{i=1}^{I}(JCi \ \cdot ti)}{Ptot}$$

where, JC represents the number of jobs created over the lifecycle of the project (jobs-y/Wh or jobs-y/J), JCi is the number of jobs created during the life cycle stage i (years), ti is the duration of employment in stage i(years), Ptot is the total energy generated over the asset life of the plant and I is the total number of lifecycle phases.

- Human health impact. The impact of human health can be measured by the number of years of life affected by disabilities (Disability Affected Life Years, or DALY) combining mortality and morbidity into a single measure [57]. The calculation of DALY is based on the sum of Years of the Life Lost (YLL) to premature death of a population and the Years Lived with Disability (YLD):

$$DALY = YLL + YLD$$
$$YLL = N \ \bullet L$$
$$YLD = (I \ \cdot LD) \cdot W = P \ \cdot W$$

where, N is the number of deaths in the population and L is the population's average remaining life expectancy, in years, at the age of death, I is the number of incident cases of a particular condition in the population, LD is the average length (duration) of disability from a particular condition, P is the prevalence of the condition, and W is the disability weight associated with the condition[30].

- Safety risks. Safety risks are usually measured in terms of fatalities resulting from accidents per unit of produced energy[58]. In reality, this indicator is based on historical data. Accidents may occur during the construction, installation, O&M and decommissioning phase of the project. In some cases, they may have catastrophic consequences for the residents near the plant. In most cases, the safety risk of an energy production plant is an issue that significantly affects the plant's social acceptability, so in any case preventive measures should be applied[59].

- Social acceptability. Acceptance of the public is a crucial aspect to consider for an energy project because it directly influences its implementation and progression. This parameter can be qualitatively assessed with an ordinal scale, indicating the anticipated level of satisfaction of the public and their opinions toward each energy technology[30].

- Allocation and tenure of land for new production. This indicator refers to the percentage of land – total and by land-use type – used for new bioenergy production where [11]:
    - A legal instrument or domestic authority establishes title and procedures for change of title; and
    - The current domestic legal system and/or socially accepted practices provide due process, and the established procedures are followed for determining legal title.

  This indicator aims to measure the percentage of land – total and by the land-use types defined in Indicator 8 (Land use and land-use change related to bioenergy feedstock production) – used for new bioenergy production for which a domestic authority or legal instrument has established title and due process and established practices are followed for establishing title. Sustainable economic and social development will be encouraged if landowners and/or users have a recognized mechanism, e.g. a legal or socially accepted instrument that secures rights to new land. This instrument can be a formal certificate of use, certificate of occupancy, or in appropriate cases a title (or joint title as needed). This indicator can serve as a way to assess how new bioenergy production influences the allocation and tenure of land. Measuring changes in land tenure can help assess how new bioenergy activities influence the social sustainability and livelihoods of various populations in developing countries. Allocation and tenure of land has both local and national considerations.

  From a social sustainability perspective, establishing and following proper land access and tenure procedures can be an important element of promoting energy access and agricultural and economic development. [11]

- Price and supply of a national food basket. This indicator describes the effects of bioenergy use and domestic production on the price and supply of a food basket, which is a nationally defined collection of representative foodstuffs, including main staple crops, measured at the national, regional, and/or household level, taking into consideration:
    - changes in demand for foodstuffs for food, feed, and fibre;
    - changes in the import and export of foodstuffs;
    - changes in agricultural production due to weather conditions;
    - changes in agricultural costs from petroleum and other energy prices; and
    - the impact of price volatility and price inflation of foodstuffs on the national, regional, and/or household welfare level, as nationally determined.

  It can be measured in: Tonnes; USD; national currencies; and percentage. In addition to bioenergy use and domestic production, numerous other factors may affect the price and supply of a food basket, including the demand for foodstuffs for food, feed and fibre; imports and exports of foodstuffs; weather conditions; energy prices; and inflation. This indicator aims to measure the impact of bioenergy use and domestic production on the price and supply of a food basket in the context of other relevant factors. [11]

- Change in income. This indicator measures the contribution of the following to change in income due to bioenergy production:
  - wages paid for employment in the bioenergy sector in relation to comparable sectors
  - net income from the sale, barter and/or own consumption of bioenergy products, including feedstocks, by self-employed households/individuals

  Its measurement units are local currency units per household/individual per year, and percentages (for share or change in total income and comparison) and local currency units per household/individual per year, and percentage (for share or change in total income). More precisely, the first goal of this indicator focuses on the wages paid for employment in the bioenergy sector in relation to comparable sectors. Employment and wages in the bioenergy sector can be important drivers of rural and social development, particularly in developing countries. In addition, wage levels provide an important indication of the labour conditions enjoyed by the people employed in this sector in relation to comparable sectors. Furthermore, the second goal of this indicator aims to measure the change in income deriving from the sale, barter and/or own consumption of bioenergy products, including feedstocks, by self-employed households or individuals. In addition to wage income, self-employment is another important source of income that can be associated with bioenergy production and through which the latter can affect rural and social development by increasing the purchasing power, diversity of livelihood options and the overall welfare of self-employed households and individuals. Net job creation and income generation in the bioenergy sector can lead to an increase in the standard of living in terms of household consumption levels and also in terms of social cohesion and stability.[11]

- Jobs in the bioenergy sector. This indicator describes the net job creation as a result of bioenergy production and use, total and disaggregated (if possible) as follows:
  - skilled/unskilled
  - indefinite/temporary.
  - Total number of jobs in the bioenergy sector; and percentage adhering to nationally recognized labour standards consistent with the principles enumerated in the ILO Declaration on Fundamental Principles and Rights at Work, in relation to comparable sectors [11]

- Change in unpaid time spent by women and children collecting biomass. It describes the Change in average unpaid time spent by women and children collecting biomass as a result of switching from traditional use of biomass to modern bioenergy services. This indicator is measured in Hours per week per household & percentage. This indicator is primarily related to the theme of Rural and social development. In most developing countries, firewood collection is an extremely time- and energy-intensive activity, particularly in remote rural areas. [11]

- Bioenergy used to expand access to modern energy services. This indicator expresses the total amount and percentage of increased access to modern energy services gained through modern bioenergy (disaggregated by bioenergy type), measured in terms of energy and numbers of households and businesses. It also describes the total number and percentage of households and businesses using bioenergy, disaggregated into modern bioenergy and traditional use of biomass. Regarding its measurement units, they can be expressed as following:

  Modern energy services can take the form of liquid fuels, gaseous fuels, solid fuels, heating, cooling and electricity. A change in access to each of these forms of modern energy can be measured in MJ per year and this is preferable in order to allow comparison of different forms of energy service, but each may also be measured in appropriate units of volume or mass per year, which may sometimes be more convenient, leading to the following possible units for this indicator component:

  1. liquid fuels: litres/year or MJ/year and percentage
  2. gaseous fuels: cubic metres/year or MJ/year and percentage
  3. solid fuels: tonnes/year or MJ/year and percentage
  4. heating and cooling: MJ/year and percentage
  5. electricity: MWh/year or MJ/year (for electricity used), MW/year (if only electricity generation capacity to which new access is deemed to have been gained can be measured), hours/year (for the time either for which electricity is used or for which there is access to a functioning electricity supply) and percentage [10].

- Incidence of occupational injury, illness and fatalities. It describes the incidences of occupational injury, illness and fatalities in the production of bioenergy in relation to comparable sectors Its measurement units are Number/ha (for comparison with other agricultural activities) or number/MJ or MW (for comparison with alternative energy sources). It refers to safety and health at work and can help providing a framework for assessing the extent to which workers are protected from work-related hazards and risks, which relates to sustainability of production in general terms. This indicator and other safety and health at work indicators are usually used by enterprises, governments and other stakeholders to formulate policies and programmes for the prevention of occupational injuries, diseases and deaths as well as to monitor the implementation of these programmes and to signal particular areas of increasing risk such as a particular occupation, industry or location, [11]

3.3 Custom-made KPIs

For the scope of this deliverable, some KPIs that were examined during the literature review should be molded into "custom-made KPIs" to achieve the goals of the CERESiS project.

Since the project is heavily focused on decontamination, the environmental indicator of Soil Quality can include some subcategories to evaluate some of the issues that are relevant to this project:

Firstly, for the agricultural stage an indicator that shows the percentage of uptake of contaminants in the soil should be considered. This indicator is also relevant to the indicator Soil Quality in the longlist of indicators.

$$Uptake\ of\ contaminants\ (\%)\ = \frac{Contaminants\ in\ Harvested\ Biomass\ (\frac{mg}{kg})}{Contaminants\ in\ Soil\ (\frac{mg}{kg})}$$

There are two main ways to extract contaminants from the soil. One method is with hyperaccumulators and the other one with fast-growing plants (high biomass plants). However, in practical terms, the mass of contaminants in soil is almost impossible to measure.

More information can be found in deliverable 1.3

More specifically, some research papers such as Antoniadis et. al and Nouri et. al used the Transfer coefficient to assess the level of soil-to-plant transfer factor from contaminant uptake from soil and the Translocation factor to assess element concentration in plant aerial biomass over element concentration in the root. [60][61]

$$Transfer\ coefficient = \frac{Element\ concentration\ in\ plant\ aerial\ biomass}{Total\ element\ concentration\ in\ soil}$$

$$Translocation\ factor = \frac{Element\ concentration\ in\ plant\ aerial\ biomass}{Element\ concentration\ in\ root}$$

It must be noted that the annual yield of the species is also important as it determines the offtake (defined as the mass removed) and the contamination levels as well. In addition, for the CERESiS project higher levels of a contaminant could be a problem for processing compared to lower concentrations. However, the mass of biomass produced is proportional to the biofuel yield. So, for the scope of CERESiS a species with high biomass productivity but a low Transfer Coefficient and Translocation Factor is better for phytostablisation. As a result, this could make the use of the Transfer Coefficient and Translocation Factor rather complicated.

According to the above a more suitable KPI could be

$$Offtake\ =\ Annual\ mass\ removal\ of\ contaminants\ in\ energy\ crops$$

Measured in kg/year.

Other soil properties such as PH, Electrical conductivity and soil nutrients will provide the end-user with a clear picture of decontamination (phytoremediation) potential of energy crops under certain soil conditions.

Furthermore, another area of focus is the processing/conversion stage of the BtL (biomass to liquid). A custom-made indicator should be considered which shows the final percentage of contaminants in the bio-oil and in the by-product. For example, in the pyrolysis process contaminants can be found in the bio-oil and in the biochar (byproduct). In addition, in the gasification process contaminants can be found in the gaseous product (syngas) and in the ash (byproduct).

$$Contaminants\ in\ Product\ (\%) = \frac{Contaminants'\ Mass\ in\ Main\ Product\ (mg)}{Contaminants'\ Mass\ in\ Harvested\ Biomass\ (mg)}$$

$$Contaminants\ in\ Byproduct\ (\%) = \frac{Contaminants'\ Mass\ in\ Byproduct\ (mg)}{Contaminants'\ Mass\ in\ Harvested\ Biomass\ (mg)}$$

Another KPI that can be customized for the scope of the CERESiS project is land-use change.

- Avoided land-use change: Defined as the area of land otherwise unsuitable for agriculture (marginal, contaminated etc) which can be successfully used for bioenergy using the CERESiS methodology
- Land under phytoremediation/management: Defined as the area of contaminated land that can be improved or managed (otherwise unsuitable for agriculture) which can be improved or managed during use for bioenergy production using CERESiS methodology

Quantifying the area that is subject to phytoremediation or phytomanagement and the area put back into productive use avoids the issue of quantifying the area of land which has been remediated. Furthermore, it must be noted that for phytoremediation the timescale is extended, there is a high uncertainty in its technical effectiveness. Lastly, phytoremediation is usually contaminant or plant specific.

Other custom-made KPIs that can be considered are:

- Nitrogen use efficiency: This indicator is the ratio of nitrogen used per tonne of biomass produced from a particular energy crop series

4 SHORTLIST OF KPIS

Considering all of the above indicators, the longlist has been filtered to form a final shortlist.

Table 1 Shortlist of CERESiS KPIs (*The Functional Unit (FU) of the LCA to be conducted within WP4 – expected adoption of $MJ_{biofuel}$ as FU)

	Name	Info	Units
Energy	Primary Energy Demand	Primary Energy required throughout the biofuel production chain. Output of several LCA Impact Assessment methodologies	MJ_{eq} / $MJ_{biofuel}$*
	Productivity	Total chain productivity. Composed by the productivity of bioenergy feedstocks by feedstock or by farm plantation, the processing efficiencies by technology and feedstock, etc. Expressed by the ratio of useful bioenergy to the land utilized.	MJ/ha
Environmental	Global Warming Potential	The effect of different GHGs to climate change, taking as reference the GWP of CO2.	kg $CO_{2\text{-}eq}$ / $MJ_{biofuel}$*
	Emissions / Impacts related to non-GHG air pollutants	Emissions of PM2.5, PM10, NOx, SO2 and other pollutants from bioenergy production, processing, transport of feedstocks, intermediate products and end products use	Relevant emission or impact / $MJ_{biofuel}$*
	Offtake of contaminants	Annual mass removal of contaminant(s) in energy crop	$kg_{contaminant}$/year
	Decontamination efficiency	The mass ratio of contaminants that remain in the final product. By-products will be also evaluated. This KPI should also assess (possibly in qualitative terms) the "manageability" of output contaminant streams.	$mg_{contaminant\_biofuel}$/$mg_{contaminant\_biomass}$
	Avoided land-use change/ land under phytoremediation	1. Defined as the area of land otherwise unsuitable for agriculture (marginal, contaminated etc.) which can be successfully used for bioenergy 2. Defined as the area of contaminated land (otherwise unsuitable for agriculture) which can be improved or managed during use for bioenergy production	m^2
Economic	Total Life Cycle Cost	The total expenditure over the whole project's life	Euros (€)
	Net Present Value	The NPV analysis brings together the TLCC and the total lifetime revenues (both discounted to base year)	Euros (€)
	Internal Rate of Return	The discount rate that sets NPV of an investment equal to zero.	(%)
	Levelized Cost of (bio) Energy	This indicator gives the minimum price for the energy produced to achieve zero economic yield (break-even price or NPV=0)	Euros (€)/$MJ_{biofuel}$
Social	Jobs Creation	It demonstrates the potential for creation of jobs associated with the project, from construction to decommissioning. It will also assess the net job creation as a result of bioenergy production and use, total and disaggregated	Number of jobs/$MJ_{biofuel}$
	Social acceptability	Acceptance of the public is a crucial aspect to consider for an energy project because it directly influences its implementation and progression. This parameter can be qualitatively assessed with an ordinal scale, indicating the anticipated level of satisfaction of the public and their opinions toward each energy technology.	Qualitatively assessed with an ordinal scale

5 CONNECTION TO RELEVANT SDG GOALS

Part of the CERESiS project is the contribution to SDG goals. The relevant SDGs that could be matched to the shortlist of KPIs are:[62]

- SDG 2: Zero Hunger
- SDG 7: Affordable and Clean Energy
- SDG 9: Industry Innovation and Infrastructure
- SDG 10: Reduced Inequalities
- SDG 11: Sustainable Cities and Communities
- SDG 13: Climate Action

Table 2: Shortlist of KPIs with relevant SDGs

	Name	Relevant SDGs
Energy	Primary Energy Demand	7,13
	Productivity	7,13
Environmental	Global Warming Potential	13
	Emissions / Impacts related to non-GHG air pollutants	13
	Offtake of contaminants	11
	Decontamination efficiency	11
	Avoided land-use change/ land under phytoremediation	2,11
Economic	Total Life Cycle Cost	7
	Net Present Value	7
	Internal Rate of Return	7
	Levelized Cost of (bio) Energy	7
Social	Jobs Creation	10

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APPENDIX

KPI Shortlist

Energy related KPIs

Group	Energy
Name	Primary Energy Demand (Fossil and Renewable)
ID	KPI_Energ_1
Description	The amount of Primary Energy (as exist in the form of resources, both fossil and renewable) required for the final biofuel production. Output of several LCA Impact Assessment methodologies.
Scope	Product, production, equipment
Formula	-
Unit of measure	MJ_{eq}/ $MJ_{biofuel}$
Range	N/A
Trend	The lower, the better
Context	
Timing	On demand
Audience	Operator, supervisor, management
Production methodology	Discrete, batch, continuous
Source	https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Primary_energy_consumption
Connection to CERESiS objectives	Energy efficiency of proposed solution

Group	Energy
Name	Productivity
ID	KPI_Energ_2
Description	Productivity of bioenergy feedstocks by feedstock or by farm plantation, processing efficiencies by technology and feedstock, amount of bioenergy and product by mass, volume, or energy content per hectare per year, production cost per unit of energy
Scope	Product, production, equipment
Formula	-
Unit of measure	MJ/ha
Range	N/A
Trend	The bigger, the better
Context	
Timing	On demand
Audience	Operator, supervisor, management
Production methodology	Discrete, batch, continuous
Source	GBEP THE GLOBAL BIOENERGY PARTNERSHIP SUSTAINABILITY INDICATORS FOR BIOENERGY; 2011;
Connection to CERESiS objectives	Energy efficiency of proposed solution

Environmental KPIs

Group	Environmental
Name	Global warming potential (GWP)
ID	KPI_Env_1
Description	This indicator represents the effect of different GHGs to climate change, taking as reference the GWP of CO_2
Scope	Product, production, equipment
Formula	$$GWP = \sum_{k}^{K} GWP_k \cdot B_k$$ K is the total number of GHGs emitted from the project GWP_k is the global warming potential of GHG B_k represents the emissions of the GHG, k, per unit of energy produced (expressed in g / J or Wh)
Unit of measure	g $CO_{2\text{-eq}}$ / J or Wh
Range	N/A
Trend	The lower, the better
Context	
Timing	On demand
Audience	Operator, supervisor, management
Production methodology	Discrete, batch, continuous
Source	Kourkoumpas, D.S.; Benekos, G.; Nikolopoulos, N.; Karellas, S.; Grammelis, P.; Kakaras, E. A Review of Key Environmental and Energy Performance Indicators for the Case of Renewable Energy Systems When Integrated with Storage Solutions. Applied Energy 2018, 231, 380–398.
Connection to CERESiS objectives	Environmental impact of proposed solution

Group	Environmental
Name	Emissions / Impacts related to non-GHG air pollutants
ID	KPI_Env_2
Description	Emissions of PM2.5, PM10, NOx, SO2 and other pollutants from bioenergy production, processing, transport of feedstocks, intermediate products, and end products use
Scope	Product, production
Formula	-
Unit of measure	Relevant emission or impact / $MJ_{biofuel}$*
Range	N/A
Trend	The lower the better
Context	
Timing	On demand
Audience	Operator, supervisor, management
Production methodology	Discrete, batch, continuous
Source	GBEP THE GLOBAL BIOENERGY PARTNERSHIP SUSTAINABILITY INDICATORS FOR BIOENERGY; 2011;
Connection to CERESiS objectives	Environmental impact of proposed solution

Group	Environmental
Name	Offtake of contaminants
ID	KPI_Env_3
Description	Annual mass removal of contaminant(s) in energy crop
Scope	Product, production
Formula	-
Unit of measure	$Kg_{contaminant}$/year
Range	N/A
Trend	The higher the better
Context	
Timing	On demand
Audience	Operator, supervisor, management
Production methodology	Discrete, batch, continuous
Source	Custom made indicator
Connection to CERESiS objectives	Soil decontamination of proposed solution

Group	Environmental
Name	Decontamination efficiency
ID	KPI_Env_4
Description	The mass ratio of contaminants that remain in the final product. By-products will be also evaluated. This KPI should also assess (possibly in qualitative terms) the "manageability" of output contaminant streams.
Scope	Product, production
Formula	-
Unit of measure	$mg_{contaminant\_biofuel}/mg_{contaminant\_biomass}$
Range	N/A
Trend	The lower the better
Context	
Timing	On demand
Audience	Operator, supervisor, management
Production methodology	Discrete, batch, continuous
Source	Custom made indicator
Connection to CERESiS objectives	Decontamination efficiency of proposed solution

Group	Environmental
Name	Avoided land-use change/ land under phytoremediation
ID	KPI_Env_5
Description	1. Defined as the area of land otherwise unsuitable for agriculture (marginal, contaminated etc.) which can be successfully used for bioenergy 2. Defined as the area of contaminated land (otherwise unsuitable for agriculture) which can be improved or managed during use for bioenergy production
Scope	Product, production
Formula	-
Unit of measure	m^2
Range	N/A
Trend	The higher the better
Context	
Timing	On demand
Audience	Operator, supervisor, management
Production methodology	Discrete, batch, continuous
Source	Custom made indicator
Connection to CERESiS objectives	Soil decontamination of proposed solution

Economic KPIs

Group	Economic
Name	Total Life-Cycle Cost (TLCC)
ID	KPI_Econ_1
Description	TLCC represents the total expenditure over the whole project's life and discounts this amount to a present value. It can include taxes if needed, and the equation must be adjusted according to the relevant tax system in operation.
Scope	Product, production, equipment
Formula	$$\mathrm{TLCC} = \mathrm{CC} + \mathrm{OC} + \mathrm{MC} + \mathrm{FC} - \mathrm{SV} - \mathrm{BP}$$ CC is the initial capital cost, OC is the operating cost, MC is the maintenance cost, FC is the feedstock costs, SV is the salvage value, and BP represents the by-product credits
Unit of measure	Euros
Range	N/A
Trend	The lower, the better
Context	
Timing	On demand
Audience	Operator, supervisor, management
Production methodology	Discrete, batch, continuous
Source	Meurah, T.; Riayatsyah, I.; Ong, H.C.; Chong, W.T. Life Cycle Cost and Sensitivity Analysis of Reutealis Trisperma as Non-Edible Feedstock For., doi:10.3390/en10070877.
Connection to CERESiS objectives	Economic viability of proposed solution

Group	Economic
Name	Net Present Value (NPV)
ID	KPI_Econ_2
Description	The discounted cash flow (DCF) valuation approach provides a basis for assessing the cash flows of a project. The total lifetime cash flows are discounted to the present or to a defined base year. The NPV analysis brings together the TLCC and the total lifetime revenues (both discounted to base year). The parameter r is the real discount rate
Scope	Product, production
Formula	$$NPV\ (€) = -CF_0 + \sum_{t=1}^{N} \frac{CF_t}{(1+r)^t}$$ N is the lifetime duration of the investment, CF_0 is the cash flow in year 0, CF_t are the free cash flows of period t, namely the difference between costs and revenues including taxes, depreciation, etc.
Unit of measure	Euros
Range	N/A
Trend	The bigger, the better
Context	
Timing	On demand
Audience	Operator, supervisor, management
Production methodology	Discrete, batch, continuous
Source	Colla, M.; Ioannou, A.; Falcone, G. Critical Review of Competitiveness Indicators for Energy Projects. Renewable and Sustainable Energy Reviews 2020, 125.
Connection to CERESiS objectives	Economic viability of proposed solution

Group	Economic
Name	Internal Rate of Return (IRR)
ID	KPI_Econ_3
Description	This is a common metric used in capital budgeting to evaluate the profitability of potential investments and it is defined as the discount rate that sets NPV of an investment equal to zero
Scope	Product, production
Formula	$$IRR(\%) = \sum_{t=1}^{LT} \frac{B_{tot,t} - C_{tot,t}}{(1+IRR)^t} = 0$$ B_{tot} are the total revenues C_{tot} are the total costs
Unit of measure	%
Range	N/A
Trend	The higher, the better
Context	
Timing	On demand
Audience	Operator, supervisor, management
Production methodology	Discrete, batch, continuous
Source	Colla, M.; Ioannou, A.; Falcone, G. Critical Review of Competitiveness Indicators for Energy Projects. Renewable and Sustainable Energy Reviews 2020, 125.
Connection to CERESiS objectives	Economic viability of proposed solution

Group	Economic
Name	Levelised Cost of (bio)Energy (LCOE)
ID	KPI_Econ_4
Description	This indicator is widely used to compare specifically bio-energy generation technologies in term of their cost competitiveness.
Scope	Product, production
Formula	$$LCOE\left(\frac{Euros}{Wh}\right) = \frac{\sum_{t=1}^{LT} \frac{C_{tot,t}}{(1+r)^t}}{\sum_{t=1}^{LT} \frac{ANEP_{biofuels}}{(1+r)^t}}$$ Where $C_{tot,t}$ is the total cost in the year t, $ANEP_{biofuels}$ is the bio-energy produced from biofuels and r is the real discount rate.
Unit of measure	Euros/Wh
Range	N/A
Trend	The lower, the better
Context	
Timing	On demand
Audience	Operator, supervisor, management
Production methodology	Discrete, batch, continuous
Source	Colla, M.; Ioannou, A.; Falcone, G. Critical Review of Competitiveness Indicators for Energy Projects. Renewable and Sustainable Energy Reviews 2020, 125.
Connection to CERESiS objectives	Economic viability of proposed solution

Social KPIs

Group	Social
Name	Jobs creation (direct and indirect)
ID	KPI_Soc_1
Description	It demonstrates the potential for creation of jobs associated with the project, from construction to decommissioning, including O&M. Direct employment refers to the jobs created directly by core activities of the energy generation project without accounting for the intermediate inputs (such as the supply of materials and financial services) necessary to manufacture the equipment, construct and operate the plant, which are covered by upstream industries supplying and supporting the core activities (indirect employment)
Scope	Product, production
Formula	$\mathrm{JC} = \frac{\sum_{i=1}^{I}(JCi \ \cdot ti)}{P_{tot}}$ JC represents the number of jobs created over the lifecycle of the project (jobs-y/Wh or jobs-y/J) JC_i is the number of jobs created during the life cycle stage i (years) T_i is the duration of employment in stage I (years) P_{tot} is the total energy generated over the asset life of the plant and I is the total number of lifecycle phases
Unit of measure	Jobs-years per Wh or Joule
Range	N/A
Trend	The higher, the better
Context	
Timing	On demand
Audience	Operator, supervisor, management
Production methodology	Discrete, batch, continuous
Source	Colla, M.; Ioannou, A.; Falcone, G. Critical Review of Competitiveness Indicators for Energy Projects. Renewable and Sustainable Energy Reviews 2020, 125.
Connection to CERESiS objectives	Social benefits of proposed solution

Group	Social
Name	Social acceptability
ID	KPI_Soc_4
Description	Acceptance of the public is a crucial aspect to consider for an energy project because it directly influences its implementation and progression. This parameter can be qualitatively assessed with an ordinal scale, indicating the anticipated level of satisfaction of the public and their opinions toward each energy technology.
Scope	Product, production
Formula	-
Unit of measure	Level of satisfaction
Range	N/A
Trend	The higher, the better
Context	
Timing	On demand
Audience	Operator, supervisor, management
Production methodology	Discrete, batch, continuous
Source	Colla, M.; Ioannou, A.; Falcone, G. Critical Review of Competitiveness Indicators for Energy Projects. Renewable and Sustainable Energy Reviews 2020, 125.
Connection to CERESiS objectives	Social benefits of proposed solution

Candidate KPIs not adopted in shortlist

Energy related KPIs (Candidate)

Group	Energy
Name	Energy Payback Time (EPBT)
ID	- (Not adopted in shortlist)
Description	This indicator expresses the time that a project needs to operate to produce the equivalent amount of energy that was required to implement it (manufacturing, construction, decommissioning, Operation and Maintenance (O&M).
Scope	Product, production
Formula	$$EPBT(y) = \frac{Er}{ANEP}$$ *Er:* (J or Watt hour (Wh)) is the direct and indirect energy required for the project *ANEP:* ((J or Wh)/y) is the Annual Net Energy Production
Unit of measure	Years (y)
Range	N/A
Trend	The lower, the better
Context	
Timing	On demand
Audience	Operator, supervisor, management
Production methodology	Discrete, batch, continuous
Source	Bhandari, K.P.; Collier, J.M.; Ellingson, R.J.; Apul, D.S. Energy Payback Time (EPBT) and Energy Return on Energy Invested (EROI) of Solar Photovoltaic Systems: A Systematic Review and Meta-Analysis. Renewable and Sustainable Energy Reviews 2015, 47, 133–141.
Connection to CERESiS objectives	Call requirement

Group	Energy
Name	Net Energy Yield
ID	- (Not adopted in shortlist)
Description	The Net Energy Yield (NEY) expresses the difference between the energy resource harvested and is useable for society (over the project's lifetime) and the energy required to extract and provide this energy
Scope	Product, production
Formula	$$NEY = Ed - Er$$ *Ed* (Wh or J) represents the energy returned to society *Er* (Wh or J) is the direct and indirect energy required to provide Ed
Unit of measure	Wh or Joule
Range	N/A
Trend	The bigger, the better
Context	
Timing	On demand
Audience	Operator, supervisor, management
Production methodology	Discrete, batch, continuous
Source	Colla, M.; Ioannou, A.; Falcone, G. Critical Review of Competitiveness Indicators for Energy Projects. Renewable and Sustainable Energy Reviews 2020, 125, 109794, doi:10.1016/j.rser.2020.109794.
Connection to CERESiS objectives	Call requirement

Group	Energy
Name	Energy Returned On (energy) invested (ERO(E)I)
ID	- (Not adopted in shortlist)
Description	EROI is the ratio of the amount of energy harvested to the total amount of energy required to provide it
Scope	Product, production
Formula	$$EROI = \frac{Ed}{Er}$$ *Ed* (Wh or J) represents the energy returned to society *Er* (Wh or J) is the direct and indirect energy required to provide Ed
Unit of measure	Ratio
Range	N/A
Trend	The bigger, the better
Context	
Timing	On demand
Audience	Operator, supervisor, management
Production methodology	Discrete, batch, continuous

Source	Colla, M.; Ioannou, A.; Falcone, G. Critical Review of Competitiveness Indicators for Energy Projects. Renewable and Sustainable Energy Reviews 2020, 125, 109794, doi:10.1016/j.rser.2020.109794.
Connection to CERESiS objectives	Call requirement

Group	Energy
Name	System Energy Returned (SER)
ID	- (Not adopted in shortlist)
Description	The SER differentiates renewable from non-renewable sources, and it assesses the efficiency of the technologies to use the inherent energy of the non-renewable feedstock. The inverse of SER represents the intensity of depletion of the stock of nonrenewable resources
Scope	Product, production
Formula	$$SER = \frac{Ed}{(Er + Ef)_{NR}}$$ *Ed* (Wh or J) represents the energy returned to society *Er* (Wh or J) is the direct and indirect energy required to provide Ed *Ef* (J) is the energy content of the feedstock, and the suffices "*NR*" stands for "non-renewable"
Unit of measure	Ratio
Range	N/A
Trend	The bigger, the better
Context	
Timing	On demand
Audience	Operator, supervisor, management
Production methodology	Discrete, batch, continuous
Source	Cordella, M.; Stramigioli, C.; Santarelli, F. A Set of Coherent Indicators for the Assessment of the Energy Profitability of Energy Systems. *Journal of Sustainable Bioenergy Systems* **2013**, *03*, 40–47, doi:10.4236/jsbs.2013.31005.
Connection to CERESiS objectives	Call requirement

Group	Energy
Name	System Energy Efficiency (SEE)
ID	- (Not adopted in shortlist)
Description	SEE is the ratio of energy unit returned to society and the overall energy resources stock
Scope	Product, production
Formula	$$SEE = \frac{Ed}{(Er + Ef)tot}$$ *Ed* (Wh or J) represents the energy returned to society *Er* (Wh or J) is the direct and indirect energy required to provide Ed *Ef* (J) is the energy content of the feedstock, and the suffice "*tot*" stands for "total"
Unit of measure	Ratio
Range	N/A
Trend	The bigger, the better
Context	
Timing	On demand
Audience	Operator, supervisor, management
Production methodology	Discrete, batch, continuous
Source	Cordella, M.; Stramigioli, C.; Santarelli, F. A Set of Coherent Indicators for the Assessment of the Energy Profitability of Energy Systems. Journal of Sustainable Bioenergy Systems 2013, 03, 40–47, doi:10.4236/jsbs.2013.31005.
Connection to CERESiS objectives	Call requirement

Group	Energy
Name	Energy Diversity
ID	- (Not adopted in shortlist)
Description	Change in diversity of total primary energy supply due to bioenergy
Scope	Product, production
Formula	Ratio
Unit of measure	MJ bioenergy per year in the Total Primary Energy Supply (values from 0 to 1)
Range	0 to 1
Trend	The bigger, the better
Context	

Timing	On demand
Audience	Operator, supervisor, management
Production methodology	Discrete, batch, continuous
Source	GBEP THE GLOBAL BIOENERGY PARTNERSHIP SUSTAINABILITY INDICATORS FOR BIOENERGY; 2011;
Connection to CERESiS objectives	Call requirement

Group	Energy
Name	Net Energy Balance
ID	- (Not adopted in shortlist)
Description	Energy ratio of the bioenergy value chain with comparison with other energy sources (energy ratios of feedstock production, processing of feedstock into bioenergy, bioenergy use and life cycle analysis)
Scope	Product, production
Formula	-
Unit of measure	Ratio
Range	N/A (comparison)
Trend	N/A
Context	
Timing	On demand
Audience	Operator, supervisor, management
Production methodology	Discrete, batch, continuous
Source	GBEP THE GLOBAL BIOENERGY PARTNERSHIP SUSTAINABILITY INDICATORS FOR BIOENERGY; 2011;
Connection to CERESiS objectives	Call requirement

Group	Energy
Name	Change in consumption of fossil fuel and traditional biomass
ID	- (Not adopted in shortlist)
Description	Substitution of fossil fuels with domestic bioenergy measured by energy content/ substitution of traditional use of biomass with modern domestic bioenergy measured by energy content
Scope	Product, production
Formula	-
Unit of measure	MJ per year and/or MW per year
Range	N/A
Trend	The bigger, the better
Context	
Timing	On demand
Audience	Operator, supervisor, management
Production methodology	Discrete, batch, continuous
Source	GBEP THE GLOBAL BIOENERGY PARTNERSHIP SUSTAINABILITY INDICATORS FOR BIOENERGY; 2011;
Connection to CERESiS objectives	Call requirement

Group	Energy
Name	Capacity and flexibility of use of bioenergy
ID	- (Not adopted in shortlist)
Description	Ratio of capacity for using bioenergy compared with actual use for each significant utilization route/ ratio of flexible capacity which can use either bioenergy or other fuel sources to total capacity
Scope	Product, production
Formula	-
Unit of measure	Ratio (comparison)
Range	N/A
Trend	The bigger, the better
Context	
Timing	On demand
Audience	Operator, supervisor, management
Production methodology	Discrete, batch, continuous
Source	GBEP THE GLOBAL BIOENERGY PARTNERSHIP SUSTAINABILITY INDICATORS FOR BIOENERGY; 2011;
Connection to CERESiS objectives	Call requirement

Environmental KPIs (Candidate)

Group	Environmental
Name	Land-use changes and requirement
ID	- (Not adopted in shortlist)
Description	This indicator shows the amount of land required per unit of energy produced (net energy) in m² / (Wh or J). The analysis can consider the land used for the energy production plant, but also for the fuel extraction when appropriate
Scope	Product, production
Formula	$$\mathrm{ILU} = \mathrm{LA} \cdot t_{LA}$$ LA (m²/J or Wh) is the total land area required for the construction and operation of the project per unit of energy produced t_{LA} is the amount of time that the land area is occupied by the project (y)
Unit of measure	$m^2 \cdot y$ / J or Wh
Range	N/A
Trend	The lower, the better
Context	
Timing	On demand
Audience	Operator, supervisor, management
Production methodology	Discrete, batch, continuous
Source	Colla, M.; Ioannou, A.; Falcone, G. Critical Review of Competitiveness Indicators for Energy Projects. Renewable and Sustainable Energy Reviews 2020, 125, 109794, doi:10.1016/j.rser.2020.109794.
Connection to CERESiS objectives	Call requirement

Group	Environmental
Name	Soil quality
ID	- (Not adopted in shortlist)
Description	This indicator is related to the percentage of land for which soil quality is maintained/improved out of total land which bioenergy feedstock is cultivated or harvested. Connected to the uptake of contaminants during growth (phytoextraction) and to the overall phytoremediation effect.
Scope	Product, production
Formula	-
Unit of measure	Percentage
Range	N/A
Trend	The bigger, the better
Context	
Timing	On demand
Audience	Operator, supervisor, management
Production methodology	Discrete, batch, continuous
Source	GBEP THE GLOBAL BIOENERGY PARTNERSHIP SUSTAINABILITY INDICATORS FOR BIOENERGY; 2011;
Connection to CERESiS objectives	Call requirement

Group	Environmental
Name	Harvest levels of wood resources
ID	- (Not adopted in shortlist)
Description	This indicator is related to the annual harvest of wood resources by volume as a percentage of net growth or sustained yield, and the percentage of annual harvest used for bioenergy
Scope	Product, production
Formula	-
Unit of measure	m^3/ha/year, tonnes/ha/year, m^3/year or tonnes/year
Range	N/A
Trend	The lower, the better
Context	
Timing	On demand
Audience	Operator, supervisor, management
Production methodology	Discrete, batch, continuous
Source	GBEP THE GLOBAL BIOENERGY PARTNERSHIP SUSTAINABILITY INDICATORS FOR BIOENERGY; 2011;
Connection to CERESiS objectives	Call requirement

Group	Environmental
Name	Water quality

ID	- (Not adopted in shortlist)
Description	Pollutant loadings to waterways and bodies attributable to fertilizer and pesticide application for bioenergy feedstock production or to bioenergy processing effluents
Scope	Product, production
Formula	-
Unit of measure	kg of N, P and active ingredient per ha per year, percentages of total N, P and pesticide active ingredient loadings from agriculture in the watershed, pollutant levels in bioenergy processing effluents in mg/l, total annual pollutant loadings in kg/year or (per watershed area) in kg/ha/year, percentage of total pollutant loadings from agricultural processing in the watershed
Range	N/A
Trend	The lower, the better
Context	
Timing	On demand
Audience	Operator, supervisor, management
Production methodology	Discrete, batch, continuous
Source	GBEP THE GLOBAL BIOENERGY PARTNERSHIP SUSTAINABILITY INDICATORS FOR BIOENERGY; 2011;
Connection to CERESiS objectives	Call requirement

Group	Environmental
Name	Biological diversity and landscape
ID	- (Not adopted in shortlist)
Description	Area and percentage of nationally recognized areas of high biodiversity value or critical ecosystems converted to bioenergy production/ of the land used for bioenergy production where nationally recognized invasive species, by risk category, are cultivated/ of the land used for bioenergy production where nationally recognized conservation methods are used
Scope	Product, production
Formula	-
Unit of measure	Percentage
Range	N/A
Trend	The lower, the better
Context	
Timing	On demand
Audience	Operator, supervisor, management
Production methodology	Discrete, batch, continuous
Source	GBEP THE GLOBAL BIOENERGY PARTNERSHIP SUSTAINABILITY INDICATORS FOR BIOENERGY; 2011;
Connection to CERESiS objectives	Call requirement

Economic KPIs (Candidate)

Group	Economic
Name	Simple Payback time (SPB) Discounted Payback Time (SER)
ID	- (Not adopted in shortlist)
Description	The simple and discounted payback period indicators specify the length of time required for the cumulative revenues to be equal to the cumulative costs, i.e., the required length time for an investment to reach its breakeven point
Scope	Product, production
Formula	$SPB\ (years) = \sum_{t=1}^{SPB} Btot,t = \sum_{t=1}^{SPB} Ctot,t$ $DPB\ (years) = \sum_{t=1}^{DPB} \frac{Btot,t}{(1+r)^t} = \sum_{t=1}^{DPB} \frac{Ctot,t}{(1+r)^t}$ Btot are the total revenues Ctot are the total costs r is the real discount rate
Unit of measure	Years
Range	N/A
Trend	The lower, the better
Context	
Timing	On demand
Audience	Operator, supervisor, management
Production methodology	Discrete, batch, continuous
Source	Colla, M.; Ioannou, A.; Falcone, G. Critical Review of Competitiveness Indicators for Energy Projects. Renewable and Sustainable Energy Reviews 2020, 125.
Connection to CERESiS objectives	Call requirement

Group	Economic
Name	Weighted Average Cost of Capital (WACC)
ID	- (Not adopted in shortlist)
Description	Represents the cost that a company must pay to raise the capital required for the implementation of the project
Scope	Product, production
Formula	$WACC = r_{eq} \cdot \frac{E_c}{V} + r_d \cdot \frac{D}{V} \cdot (1-T)$ E_c is the market value of equity D is the market value of debt $V = E_c + D$ r_{eq} denotes the return on equity r_d is the interest rate on debt T is the corporate tax rate
Unit of measure	Euros
Range	N/A
Trend	The lower, the better
Context	
Timing	On demand
Audience	Operator, supervisor, management
Production methodology	Discrete, batch, continuous
Source	Colla, M.; Ioannou, A.; Falcone, G. Critical Review of Competitiveness Indicators for Energy Projects. Renewable and Sustainable Energy Reviews 2020, 125.
Connection to CERESiS objectives	Call requirement

Group	Economic
Name	Benefits to Costs Ratio (BCR)
ID	- (Not adopted in shortlist)
Description	This is an indicator composed of the ratio between the discounted benefits and costs over a period of time
Scope	Product, production
Formula	$BCR = \frac{\sum_{t=1}^{LT} \frac{B_{tot,t}}{(1+r)^t}}{\sum_{t=1}^{LT} \frac{C_{tot,t}}{(1+r)^t}}$ Btot are the total revenues Ctot are the total costs

	r is the real discount rate
Unit of measure	Ratio
Range	N/A
Trend	The bigger, the better
Context	
Timing	On demand
Audience	Operator, supervisor, management
Production methodology	Discrete, batch, continuous
Source	Colla, M.; Ioannou, A.; Falcone, G. Critical Review of Competitiveness Indicators for Energy Projects. Renewable and Sustainable Energy Reviews 2020, 125.
Connection to CERESiS objectives	Call requirement

Group	Economic
Name	Gross value added
ID	- (Not adopted in shortlist)
Description	It describes the gross value added per unit of bioenergy produced and as a percentage of gross domestic product
Scope	Product, production
Formula	Gross value added = Total output value - Intermediate inputs
Unit of measure	Euros/MJ
Range	N/A
Trend	The bigger, the better
Context	
Timing	On demand
Audience	Operator, supervisor, management
Production methodology	Discrete, batch, continuous
Source	GBEP THE GLOBAL BIOENERGY PARTNERSHIP SUSTAINABILITY INDICATORS FOR BIOENERGY; 2011;
Connection to CERESiS objectives	Call requirement

Social KPIs (Candidate)

Group	Social
Name	Human health impact
ID	- (Not adopted in shortlist)
Description	The impact of human health can be measured by the number of years of life affected by disabilities (Disability Affected Life Years, or DALY) combining mortality and morbidity into a single measure
Scope	Product, production
Formula	DALY is based on the sum of Years of the Life Lost (YLL) to premature death of a population and the Years Lived with Disability (YLD) $DALY = YLL + YLD$ $YLL = N \bullet L$ $YLD = (I \cdot LD) \cdot W = P \cdot W$ where, N is the number of deaths in the population and L is the population's average remaining life expectancy, in years, at the age of death, I is the number of incident cases of a particular condition in the population, LD is the average length (duration) of disability from a particular condition, P is the prevalence of the condition, and W is the disability weight associated with the condition
Unit of measure	Years affected by disability
Range	N/A
Trend	The lower, the better
Context	
Timing	On demand
Audience	Operator, supervisor, management
Production methodology	Discrete, batch, continuous
Source	Colla, M.; Ioannou, A.; Falcone, G. Critical Review of Competitiveness Indicators for Energy Projects. Renewable and Sustainable Energy Reviews 2020, 125.
Connection to CERESiS objectives	Call requirement

Group	Social
Name	Safety risks
ID	- (Not adopted in shortlist)
Description	Safety risks are usually measured in terms of fatalities resulting from accidents per unit of produced energy. In reality, this indicator is based on historical data. Accidents may occur during the construction, installation, O&M and decommissioning phase of the project. In some cases, they may have catastrophic consequences for the residents near the plant. In most cases, the safety risk of an energy production plant is an issue that significantly affects the plant's social acceptability, so in any case preventive measures should be applied
Scope	Product, production
Formula	-
Unit of measure	Fatalities from accidents per unit of bioenergy
Range	N/A
Trend	The lower the better
Context	
Timing	On demand
Audience	Operator, supervisor, management
Production methodology	Discrete, batch, continuous
Source	Santoyo-castelazo, E.; Azapagic, A. Sustainability Assessment of Energy Systems: Integrating Environmental , Economic and Social Aspects. Journal of Cleaner Production 2020, 80, 119–138, doi:10.1016/j.jclepro.2014.05.061.
Connection to CERESiS objectives	Call requirement

Group	Social
Name	Allocation and tenure of land for new production
ID	- (Not adopted in shortlist)
Description	This indicator refers to the percentage of land-total and by land-use-type used for new bioenergy production where a legal instrument or domestic authority establishes title and procedures for change of title
Scope	Product, production
Formula	-
Unit of measure	Percentage
Range	N/A
Trend	The higher, the better
Context	
Timing	On demand

Audience	Operator, supervisor, management
Production methodology	Discrete, batch, continuous
Source	GBEP THE GLOBAL BIOENERGY PARTNERSHIP SUSTAINABILITY INDICATORS FOR BIOENERGY; 2011;
Connection to CERESiS objectives	Call requirement

Group	Social
Name	Price and supply for national food basket
ID	- (Not adopted in shortlist)
Description	This indicator describes the effects of bioenergy use and domestic production on the price and supply of the food basket
Scope	Product, production
Formula	-
Unit of measure	Tonnes, Euros, national currencies and percentage
Range	N/A
Trend	The lower, the better
Context	
Timing	On demand
Audience	Operator, supervisor, management
Production methodology	Discrete, batch, continuous
Source	GBEP THE GLOBAL BIOENERGY PARTNERSHIP SUSTAINABILITY INDICATORS FOR BIOENERGY; 2011;
Connection to CERESiS objectives	Call requirement

Group	Social
Name	Change in income
ID	- (Not adopted in shortlist)
Description	This indicator measures the change in income due to bioenergy production
Scope	
Formula	-
Unit of measure	Local currency units per household/individual per year, and percentages (for share or change in total income and comparison) and local currency units per household/individual per year, and percentage (for share or change in total income)
Range	N/A
Trend	The higher, the better
Context	
Timing	On demand
Audience	Operator, supervisor, management
Production methodology	Discrete, batch, continuous
Source	GBEP THE GLOBAL BIOENERGY PARTNERSHIP SUSTAINABILITY INDICATORS FOR BIOENERGY; 2011;
Connection to CERESiS objectives	Call requirement

Group	Social
Name	Jobs in the bioenergy sector
ID	- (Not adopted in shortlist)
Description	This indicator describes the net job creation as a result of bioenergy production and use, total and disaggregated
Scope	Product, production
Formula	-
Unit of measure	Number of jobs
Range	N/A
Trend	The higher, the better
Context	
Timing	On demand
Audience	Operator, supervisor, management
Production methodology	Discrete, batch, continuous
Source	GBEP THE GLOBAL BIOENERGY PARTNERSHIP SUSTAINABILITY INDICATORS FOR BIOENERGY; 2011;
Connection to CERESiS objectives	Call requirement

Group	Social
Name	Change in unpaid time spent by women and children collectiong biomass

ID	- (Not adopted in shortlist)
Description	It describes the change in average unpaid time spent by women and childern collecting biomass as a result of switching from traditional use of biomass to modern bioenergy services
Scope	Product, production
Formula	-
Unit of measure	Hours per week per household & percentage
Range	N/A
Trend	The bigger, the better
Context	
Timing	On demand
Audience	Operator, supervisor, management
Production methodology	Discrete, batch, continuous
Source	GBEP THE GLOBAL BIOENERGY PARTNERSHIP SUSTAINABILITY INDICATORS FOR BIOENERGY; 2011;
Connection to CERESiS objectives	Call requirement

Group	Social
Name	Bioenergy used to expand access to modern energy services
ID	- (Not adopted in shortlist)
Description	This indicator expresses the total amount and percentage of increased access to modern energy services gained through modern bioenergy, measured in terms of energy and numbers of households and businesses
Scope	Product, production
Formula	-
Unit of measure	litres/year, cubic metres/year, tonnes/year, MJ/year, MWh/year, percentage
Range	N/A
Trend	The higher, the better
Context	
Timing	On demand
Audience	Operator, supervisor, management
Production methodology	Discrete, batch, continuous
Source	GBEP THE GLOBAL BIOENERGY PARTNERSHIP SUSTAINABILITY INDICATORS FOR BIOENERGY; 2011;
Connection to CERESiS objectives	Call requirement

Group	Social
Name	Incidence of occupational injury illness and fatalities
ID	- (Not adopted in shortlist)
Description	It describes the incidences of occupational injury, illness and fatalities in the production bioenergy in relation to comparable sectors
Scope	Product, production
Formula	-
Unit of measure	Number/ha (for comparison with other agricultural activities) or number/MJ or MW (for comparison with alternative energy sources)
Range	N/A
Trend	The lower, the better
Context	
Timing	On demand
Audience	Operator, supervisor, management
Production methodology	Discrete, batch, continuous
Source	GBEP THE GLOBAL BIOENERGY PARTNERSHIP SUSTAINABILITY INDICATORS FOR BIOENERGY; 2011;
Connection to CERESiS objectives	Call requirement